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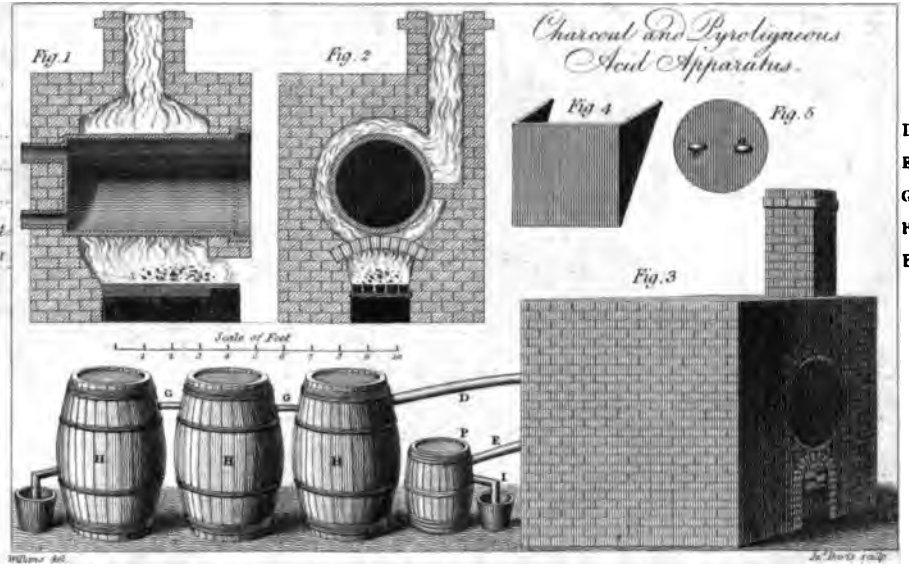
FROM

Samuel L. Dana,
of Lowell.

13 Feb. 1861.

Plate XII

1. Cylinder
2 Diff.t Section
3. Elevation
4 Outer Stopper
5. Inner Shut.r



D. Acid. Pipe
E. Tar D.o
G. Adapters
H. Acid Casks
P. Tar receiver

CHEMICAL ESSAYS,

PRINCIPALLY RELATING TO

THE ARTS AND MANUFACTURES

OF

THE BRITISH DOMINIONS.

170-29-2

By SAMUEL PARKES, F.L.S. M.R.I. F.S.A. Ed.

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&c &c.

THE SECOND EDITION,

Greatly enlarged, and illustrated with twenty-four Plates of Machinery and Chemical Apparatus.

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DESCRIPTION OF THE PLATES

IN

THE SECOND VOLUME.

PLATE XII.

APPARATUS for making charcoal and distilling pyroligneous acid.

Fig. 1 represents a section of a charcoal cylinder when fixed within the furnace. It is cut lengthwise through the middle, to show the internal work.

Fig. 2 is a contrary section of the same cylinder, the end, or front wall being in this case taken away to show how the fire plays round it before it passes off by the chimney.

Fig. 3 is an elevation of the building which incloses a cylinder when properly fixed, together with the fire-place, the tubes to carry off the acid and gas, the wine casks to receive pyroligneous acid, &c. complete.

Fig. 4. The outer shutter, to contain the stopping or luting which makes the cylinder air-tight during the operation of distilling the acid and charring the wood.

Fig. 5. The inner shutter, or stopper to prevent the stopping from getting among the charcoal.

PLATE XVI.

This drawing is the representation of a reverberatory furnace for preparing alkalies. The peculiar advantage of this furnace in preference to the one described in Plate XVII. consists in the arch by which it is covered. It will be observed that this arch springs from the ground, instead of from the floor of the oven which is usual; and this has the effect of binding the brick-work together much better than it can be done by bands of iron or by any other expedient. When the abutments are good, and

the arch properly loaded, such a furnace will endure much longer than any of those on the usual construction. The whole is drawn to a scale of $\frac{1}{4}$ of an inch to a foot, and the separate parts may be thus described:

A is the door by which the oven is charged.

B B the bridge which divides the oven from the fire-place. It is of a considerable thickness, and measures 9 inches from the top to the floor of the oven.

C C the ash-pit.

D an iron damper for regulating the draught of the fire-place.

E is the passage from the oven to the chimney.

G is the floor of the oven, which should be paved with the best fire-bricks set on edge, or covered with a thick plate of iron. The latter mode is the best, when it is intended to be employed for decomposing the sulphates of soda or potash.

H is the fire-place closed by an iron hopper as described at page 158, vol. i.

I the fire bars of the same construction as those mentioned in describing Plate XVII.

K K K the main arch which covers the whole of the furnace. The part below the floor of the oven may be built with good stock-bricks; but those parts which are within reach of the fire must be composed of the best fire-bricks.

L is a line upon the brick-work of the elevation, which has been engraved to show the altitude of the oven-floor.

PLATE XVII.

The elevation and plan of a reverberatory furnace on an improved construction. The separate parts may be thus described:

A is the door by which the oven is charged, the size of which may with convenience be 9 inches by 12 inches.

B B B are three strong iron bands which go on each side of the furnace. These are fastened together by cross bars of iron which go through the brick-work of the furnace, and over the top of it, and are bound tight against the walls by screws and bars, as shown in the engraving.

C the ash-pit.

D an iron damper which runs within a groove in the brick-work of the chimney, to regulate the draught or entirely stop it at pleasure.

E the passage from the oven to the chimney.

F is a faint line on the wall of the elevation to show how the arch of the roof lessens in height as it approaches the chimney. This is designed for throwing the flame more down upon the

materials before it enters the chimney, and has the effect of rendering the temperature of the oven the same in all its parts.

G is the floor of the oven, 4 feet long and 2 feet 2½ inches wide.

H is the fire-place with an iron hopper such as is described at page 158, vol. i.

I are the fire bars, with their ends projecting, as shown in the elevation, for the convenience of drawing them easily whenever it may be necessary either to cool the furnace or take out the clinkers. When the bars of a furnace are fixed in this manner, they may be readily taken out with a pair of tongs, and then the whole of the contents of the fire-place will fall into the ash-pit.

K is the bridge which divides the floor of the oven from the fire-place. This should be 14 inches thick and 9 inches high, and built with the best fire-bricks. It is important to build it with very *close* joints and with fire clay instead of mortar, as the bridge usually wants repair before any other part of the furnace.

As this drawing is an exact representation of a very useful reverberatory furnace which was erected at my own manufactory, it may perhaps be acceptable if I annex the measures of the principal parts, for the guidance of those persons who may be desirous of constructing a similar furnace.

The whole length measured on the outside is 8 feet, the width 4 feet 2 inches, and the height from the floor to the top of the covering 4 feet 6 inches. The fire-place 17 inches by 20 inches, the ash-pit 10 inches wide, and 2 feet 4 inches from the ground to the underside of the fire-bars. The height of the oven from the floor of it to the underside of the arch is 17 inches at the bridge, and 12 inches if measured at the chimney. The measures of the oven floor, the door and the bridge, have been noticed before.

PLATE XVIII.

This plate contains a collection of some of the most useful chemical utensils which can be made in earthenware. They may thus be briefly described:

A is an earthenware still in two parts, with a ledge round the neck of the body to hold lute or water, as may be most suitable to the operation to be performed in it.

B a sieve of earthenware in three parts. 1 is the sieve part with a groove round the bottom for the convenience of adapting a piece of muslin to it in the usual way. 2 is the cover which fits in tight to prevent any dust escaping during its agitation; and 3 is the vessel adapted to No. 1, for receiving such parts

of the powder to be sifted which passes through the muslin. The only advantages which this utensil has over those in common use consist in its superior cleanliness, and in the ease with which light powders may be brushed out of it.

C are crucibles both open and covered.—Those made with Wedgwood's fire ware are for some purposes preferable to any others.

D is an air-tight jar with a lid applicable to many useful purposes. 4 is a ledge running round the inside of the jar. 5 is a trough round the outside of the jar to receive the lid. When the lid is put on, the trough is to be filled with mercury, oil, water, or putty, in order to make the whole air-tight. 6 is the cover with holes to receive tubes if necessary, or they may be closed by earthen stoppers.

E an adapting tube of earthenware useful for many purposes in a laboratory.

G a galvanic trough of queen's ware for experiments in Voltaic electricity.

P a pneumatic trough of earthenware with a shelf, &c. of the usual construction.

R an earthenware retort of the usual form.

PLATE XIX.

Is the representation of crown glass in its various states from the time it is taken out of the furnace until it becomes a perfect circular sheet of window glass. The whole is fully explained in the Essay, page 195.

PLATE XX.

Apparatus for the preparation of oxymuriate of soda, oxymuriate of magnesia, &c. for the use of calico-printers.

A is the furnace for heating the materials which furnish the oxymuriatic gas.

B a cast-iron vessel containing water, and forming a water-bath for the reception of the still marked C.

C the body of the still, which should be made of lead, and properly adapted both in form and size to the cast-iron water-bath in which it stands. d d are water lutes for the top of the still to drop into; a convenient contrivance for keeping the apparatus tight, and preventing the gas from escaping into the atmosphere.

E the top or head of the still, made of lead, and sufficiently large to allow of its dipping six inches into the gutter of water

which surrounds the still. By this simple contrivance the head can be put on or taken off at pleasure and without difficulty. f f f are pipes and lutes for the different parts of the apparatus.

G G is a stirrer, with a square frame of wood covered with lead, attached to it for the purpose of agitating the materials within the still.

H a bent funnel passing through the cover of the still, for pouring in the diluted sulphuric acid.

I is a small intermediate vessel, partly filled with water, and designed to arrest any uncombined muriatic acid which may occasionally arise from the still during the process.

K represents the large receiver of lead charged with the alkaline solution. This prepared liquor is intended to receive and absorb all the oxymuriatic acid gas that comes from the still, and when sufficiently saturated it is drawn off by the cock N for use.

L is an opening for filling the reservoir, occasionally cleansing it out, &c.

M M M the agitator for constantly stirring the alkaline solution, and which is necessary to promote the absorption of the gas. In large works this is moved by a power from the steam engine.

N is the cock for drawing off the finished liquor as mentioned above.

The glass bottle, which appears in the same plate, contains two bubbles of glass; one is seen at bottom, the other floating on the surface of the liquor. This is recommended as a small and useful apparatus for ascertaining the specific gravity of the oxymuriate of soda. Its advantages, together with the mode of using it, are fully described in Vol. I. page 236.

PLATE XXI.

Is descriptive of an apparatus for bleaching cotton goods. Fig 1 is a section of the bucking apparatus, which may be thus described.

A is the boiler for heating the alkaline lye.

B represents a very large wooden vessel in which the calicoes are placed.

C the cock and pipe, by means of which the hot lye is conveyed upon the goods.

D is a square box designed for spreading the lye over the calicoes within the vessel B.

E a pump for raising the liquor again out of the vessel B, from whence it is conveyed by the spout I back into the boiler A.

F is the furnace for heating the lye.

G represents the false bottom of the calico vessel, full of holes for the passage of the lye when it has run through the goods under operation.

H is a round wooden staff which completely fits a hole at the bottom of the bucking vessel. It is called a duck, and is intended to be pulled up whenever it is designed to run off the spent alkaline liquor.

I is the spout for conveying the liquor back to the boiler as above mentioned. In some houses the boiler is fixed below the bucking vessel, and the pump is placed within the boiler as described in page 271.

Fig. 2 is the representation of a common whale-boiler.

A is a metallic boiler to be fixed in brick-work, similar to that in fig. 1.

B B is the top part of wood, called a crib, with the bottom full of holes. In this the calicoes are placed one above another, often amounting to many hundred pieces at one operation.

C is the pipe through which the lyes boil up, and d d is the umbrella suspended over the pipe for the purpose of spreading the lyes more effectually as they fall down again upon the goods.

This apparatus for bleaching possesses several advantages. The perforated wooden vessel preserves the calicoes from being injured by coming in contact with the boiler, while the pressure occasioned by so great a weight of goods frequently increases the temperature of the lye by some degrees higher than it would acquire in an *open* vessel, and this additional heat has a powerful effect in bleaching. By this contrivance there is no necessity for pumping; for, so long as the lye in the vessel A actually boils, a constant stream will flow through the pipe C upon the goods in B, and thus a perpetual circulation may be kept up till the goods have attained the desired whiteness.

PLATE XXII.

Is descriptive of some peculiar modes of purifying water. Figs. 1, 2, and 3, represent a glass apparatus invented by Mr. Pepys for filtering small quantities of water or other fluid, and may be thus described.

Fig. 2 is a glass vessel with a rib of tinned iron going round the inside of it near the top. This rib has many notches upon it, and these are designed for receiving a number of small glass rods as shown in the drawing, fig. 1. These are intended for supporting a sheet of filtering paper or any other kind of filter which may be placed within the jar. When this vessel is charged with the liquor proposed to be filtrated, the cover d, which

completely fits it, is put on to preserve the contents from dust or other accidental impurities.

Fig. 3 is a glass vessel for receiving the fluid as it filtrates from No. 2; therefore, when the apparatus is to be used, the two vessels are adapted to each other, the parts marked a and b being accurately ground to fit; and when put together, the whole, except the top, has the appearance as shown at fig. 1. This apparatus is sold by Messrs. Knight, of Foster Lane, the price 1*l.* 11*s.* 6*d.* to 2*l.* 2*s.* each, according to their size, &c.

Fig. 4 is a section of an improved water reservoir, fitted up some time ago on a large scale in Scotland.

A is a flexible pipe of leather for the purpose of allowing the tube B to alter its position according to the height of the water within the reservoir.

B is a metallic tube with a rose-head, to allow of the passage of water, and yet prevent the entrance of impurities which might accidentally float upon its surface.

C is a hollow ball of copper swimming on the water for the purpose of keeping the rose-head always near the surface, in order that no water may be ever drawn but what comes from the surface of the reservoir.

D E is a wooden trough for carrying off the waste water, and preventing the overflow of the reservoir.

F is a large iron pipe for conveying the water from the spring into the trough G, firmly fixed within the reservoir.

For the advantages of this peculiar construction of a water tank, see pages 374 and 394, &c.

PLATE XXIII.

This is a plan of a convenient apparatus first employed at Paris for the production of sal-ammoniac.

A A are two furnaces for decomposing common salt, each 14 feet long by 7 feet 6 inches wide.

B B B B are pipes of bricks, each 2 feet wide, which go through the wall dividing the workshops, and conduct the vapours of muriatic acid gas into the chamber C.

C is the leaden chamber where the muriatic acid gas and the ammoniacal gas meet for the production of muriate of ammonia, or sal-ammoniac.

D D are flues belonging to the two furnaces A A for carrying off the smoke of the fire-places. These are 14 inches by 24 inches each, and are carried up together, and at last united into one chimney above the top of the building.

E E are pipes belonging to the two furnaces A, each 14 inches wide, connected with the chimneys, and designed for

carrying off the muriatic acid gas by that conveyance into the atmosphere, when the furnaces are used for the production of soda without making sal-ammoniac.

F F are cast-iron plates or dampers, which open or shut the communication of the pipes E with the chimneys at pleasure.

G G are similar iron dampers which cut off or determine the passage of the muriatic acid gas into the leaden chamber C.

H is a ground plan of the kiln for burning the animal matters designed to produce ammonia.

J a leaden pipe to convey the ammoniacal gas into the chamber C.

K is a hole through the arch or superior part of the kiln, which is designed to receive an eolipile from whence the steam of hot water is forced into the chamber C, at the same moment when the acid and alkaline gases are entering the same receptacle.

M the kiln chimney.

N is a flight of steps leading to the ash-pan.

O a pipe by which the chamber is emptied of the liquid muriate of ammonia when necessary.

P a flight of steps leading under the chamber C.

Q a door to enter into the said chamber.

The peculiar advantage of this apparatus is, that while the muriatic acid gas is passing into the chamber C, at that moment another stream of ammoniacal gas is entering the same chamber from the kiln H, which occasions a mutual condensation and prevents any loss. For further particulars see page 453 of this volume.

PLATE XXIV.

This plate contains two representations of Mr. Lucas's furnace for converting cast-iron cutlery to good steel cutlery.

Fig. 1 is a front view of the furnace complete.

B B are cast-iron bearers for supporting the grate bars.

D foundation wall below the floor of the work-shop for supporting the interior of the furnace.

E E the two fire-places for heating the furnace. 2 is the dome or arch of the furnace. 3 3 the internal side of the front wall, in which is an aperture 4, by which the workman enters to place the iron cylinders holding the goods. This being done, the aperture is walled up as shown in the engraving, except two holes left in the bottom of the wall marked 5 5.

H is the chimney for conveying away the smoke of the fire-places.

Fig. 2 is a perpendicular section of the same furnace, presenting a side view of its internal parts, and showing how the

iron cylinders which hold the cast-iron cutlery are exposed to the action of the fire. The several parts may be thus described:

A shows the length and depth of the ash-pit.

B is the representation of one of the grate bars at full length.

E the fire-place.

F the opening for supplying the fire with fuel.

G a dotted line to show the height of the shop floor.

I I the outside wall of the furnace.

K K the iron cylinders as they stand 3 in height in the furnace, the lowermost of which are raised a few inches from the platform by being placed on pieces of brick, the intention of which is to afford the fire access to every part of them. In describing the other parts of this furnace it may be said, that 2 is the dome of the furnace; 4 is the temporary wall which is built up to close the aperture spoken of in describing the elevation fig. 1, and which in that drawing is marked 4: 5 is one of the holes left at the bottom of the said wall: 7 is another temporary wall of loose bricks; 6 is the space between the two walls; 8 the chimney; 9 an opening in the outer wall, the same width as 4; 10 a cast-iron bearer reaching across the opening to support the front of the chimney.

PLATE III.

APPARATUS FOR BOILING BY MEANS OF THE CIRCULATION OF HEATED OIL.

Fig. 1 is an elevation of the apparatus, which may be thus described:

A is a wrought-iron vessel for heating the oil, similar to the boiler of a steam engine. It is set in brick-work, with a fire under it of a moderate size, and without any flues round the sides, so that the whole action of the fire is upon the bottom. It is made of an oblong form, and its length should exceed its breadth as much as the situation in which it is placed will allow. The size depends upon the quantity of oil to be heated, or the liquor which is to be evaporated, and it is observable that the more the surface presented to the fire exceeds the evaporating surface, the greater will be the economy of fuel. Whale oil, free from sediment, is found to answer better than any other for this purpose, and the quantity necessary to be employed, is merely sufficient to cover the bottom of the vessel to the depth of six or eight inches.

B is a thermometer for ascertaining the heat of the oil.

C is a small tube opening at the lower end into the oil vessel, while the upper extremity passes into a long flue, called a steam vent, and communicating with the atmosphere. This pipe

serves three different purposes: the first is, that before the pump begins to work in the morning, there is a quantity of air contained in it, and it is necessary that there should be a vent for that, when the pump is set to work, in order to prevent any compression in the inside of the vessel. The next is, that with a common suction pump it is necessary there should be a communication with the atmosphere. Thirdly, it is designed to carry off the aqueous vapour from the fresh oil, which has a very bad smell, and such vapours would injure the sugars, if they got abroad in the sugar-house.

D is a cast-iron pump with a spring metallic piston communicating with the oil-vessel A, by means of its suction pipe E. It is set in motion in the usual manner, by some mechanical power.

F is a copper vessel, the bottom of which is covered in the inside by a coil of pipe, communicating at one of its ends with the pump at G, and at the other end with the oil vessel through the pipe H. Through this coil of pipe, the heated oil circulates, and being surrounded on all sides by the liquid in the pan F, it gives out about 100° of its heat in its passage, and returns to the oil vessel to obtain a fresh increase of temperature. This pan is surrounded by brick- or wood-work, to prevent cooling. Of course it has no fire under it.

Fig. 2 is a ground plan of the same apparatus in which the coil of pipe in the evaporating vessel F may be seen.

A is the oil vessel in which are inserted the thermometer B and the vent pipe C.

D is the pump.

E, G. The pipes forming the communication between the oil vessel and evaporating pan, which, after circulating in the form of a coil, passes out at the centre of the bottom, and returns to the oil vessel by the pipe H.

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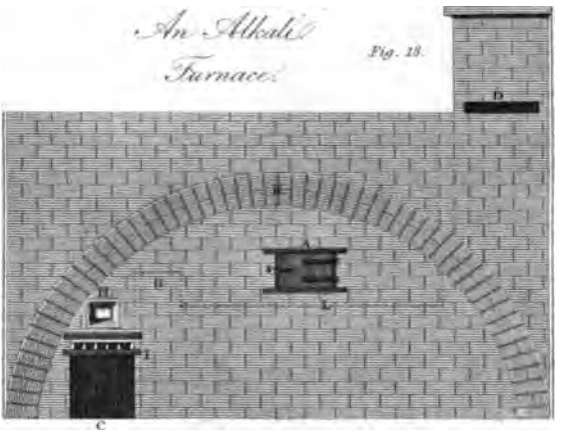
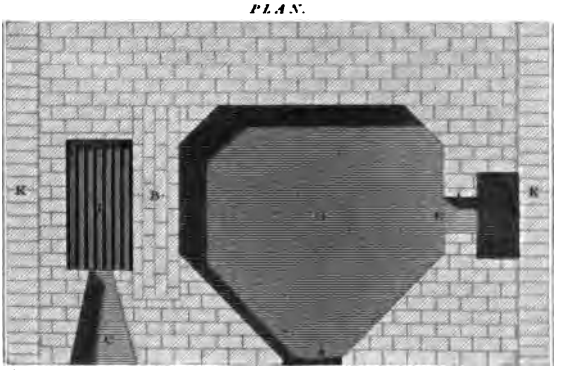
An Alkali Furnace. Fig. 18.



PLAN.

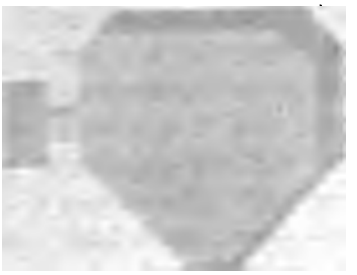


A. Furnace Door
BB. Bridge of furnace
CC. The Ash pit
D. Damper in chimney
E. Passage to the chim.y
G. Hearth of furnace
H. The fire place
I. Fire Bars
KKK. The main arch
L. Altitude of floor

ESSAY IX.

ON

THE FIXED ALKALIES.



ESSAY IX.

ON

THE FIXED ALKALIES.

FROM the nature and origin of this class of bodies, it is evident that mankind must have arrived at a considerable degree of civilization before either of the alkalies could have been brought into general use: we shall, however, be able to demonstrate that they were employed in very remote periods of antiquity.

To those who are unacquainted with chemical subjects, and who have never had an opportunity of examining these substances, it will be impossible to convey a full idea of their nature and properties by any description that can be given of them; though it may be said, that when in a state of purity, their chief characters are, an acrid and peculiar taste; that they have the property of changing blue vegetable juices to a green; have a great affinity for animal and vegetable oils, with which they unite

to form soap, the oils, or other fatty substances, being in this way rendered miscible with water; that they themselves are also very soluble in water; and lastly, which is one of their most decisive characteristics, that they readily combine with and neutralize the acids, forming neutral salts, which differ in their appearances and properties according to the nature of the respective acids, or alkalies, of which the salts are composed.

There are only three proper alkalies at present known, *viz.* the two fixed alkalies [1], and the volatile alkali. The former, which are known by the names of potash and soda, will constitute the principal subject of the present Essay.

The word *lixivium*, which was in use among the ancient Romans, is evidently derived from *lix*, which signifies a lye made with ashes: it therefore appears that the preparation of the fixed alkalies from the ashes of certain burnt vegetables, must have been known very early; especially as *lixa*, another Latin term, signifies a worker in ashes. Both of these words are used in the same acceptation by Columella [2] and also by Pliny [3], who flourished in the century immediately preceding the commencement of the Christian era.

Marcus Terentius Varro, the renowned Roman general, who wrote in the first century, affords other evidence to the same purpose; for he tells us

[1] Lithia, which has been discovered since this Essay was written, will be noticed hereafter.

[2] lib. xii. cap. 41. [3] *Nat. Hist.* lib. xiv. cap. 2.

that some of the inhabitants upon the Rhine, being in want of sea-salt, used a substitute which they procured from some species of wood [4]. These people had probably learnt a method of neutralizing the alkali which their forests afforded them, so as to form a salt that would answer some of the purposes to which our culinary salt is generally applied.

That the ancient Romans were acquainted with the fixed alkalies, or with one of them at least, is evident from a circumstance that occurred in exploring one of the streets of the ancient city of Pompeii, which was overwhelmed by an eruption of Vesuvius in the 79th year of the Christian era. On examining the excavations that were made on the spot where this famous city formerly stood, a complete soap-boiler's shop was discovered, with soap in it which had evidently been made by the combination of oil and an alkali. This soap was still perfect, though it had been manufactured more than seventeen hundred years [5].

Aristotle, who flourished nearly four hundred years before Christ, says that the ashes of certain burnt reeds and bulrushes, when macerated in water, yield a plentiful supply of salt [6]: and according to one of the sacred writers, who lived still earlier, his cotemporaries were not only acquainted

---

[4] Varro *De Re Rustica*, lib. i. cap. 7.
[5] See Miss Starke's *Letters from Italy*.
[6] *Meteor* ii. cap. 3.

with the alkalies, but had learnt to apply them to some of the common purposes of life[7].

It does not with certainty appear which of the fixed alkalies was first known, though I conceive there is some reason for assigning the priority to soda as having been first in use for domestic purposes, as nature affords it to the inhabitants of several parts of the East without any contrivance or preparation of their own. It appears likewise to have been known by the term *nitrum*[8], and it is so described by several of the ancient writers.

In the ninth century, an Arabian author of the name of Geber describes soda very distinctly, and actually distinguishes it from potash. But, on the other hand, Pliny has as plainly told us that the Germans of his day used potash in making soap; so that the matter of priority will probably ever remain in uncertainty.

The word *alkali* is of Arabian origin, and is derived from Kali, the name of a species of vegetable from which soda is generally extracted. If we believe Albertus Magnus[9], the word signifies *fæx amaritudinis*, "the dregs of bitterness;" the particle AL having, as he says, been added by the Arabs,

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[7] "Though thou wash thee with natron, and take thee much soap, yet thine iniquity is marked before me." *Jeremiah* ii. 22.

[8] Mr. Delaval, in the preface to his ingenious work entitled "*An Experimental Inquiry into the Cause of the Changes of Colours in opake and coloured Bodies*," remarks that "the nitrum of the ancients is sufficiently characterized and distinguished from the modern nitre, by its readily forming glass, when mixed with sand, and exposed to the fire." Mr. Delaval

with the design of expressing the superiority of the article obtained from the plant over the plant itself [10]. In the days of Pliny the word Kali was, throughout Egypt, generally used to signify a certain vegetable abounding in alkaline salt, which grew on the sea-shore, on the banks of the Nile, and on the confines of the river Belus in Syria [11]. The same word is in use also with us, and has the same signification.

The alkalies have a very peculiar taste, so different from that of all other bodies, that it will be no difficult matter for the student, when he has once made himself acquainted with it, to recognise them at all times by this peculiarity alone: but as these substances, when in a dry and pure state, are very corrosive, and would not fail to blister the tongue, it will always be necessary, for this purpose, to dilute them plentifully with water.

A little soda, or American pearlash, on the point of a penknife, might be dissolved in a wine-glass of water, and then tasted with safety. This small quantity will flavour the water sufficiently, and exhibit the taste which I have just noticed as peculiar to this class of substances.

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probably did not know that our nitre, when mixed with sand, and exposed to the fire, will make good glass. For an explanation of this, see the Essay on Glass in this volume.

[9] *Theatrum Chemicum*, ii. 470. Thomson, 8vo, 1804, vol. i. 463.

[10] Fourcroy's *System of Chemistry*, vol. ii. 253.

[11] Dallowe's Edition of Boerhaave's *Elements of Chemistry*, 4to, vol. i. page 440.

It is another property belonging to the alkalies, that they change many of the blue vegetable juices, such as the violet and mallow flowers, to a green; though if litmus be treated with either potash or soda, the colour will be rendered rather more intensely blue. By making this experiment, which may be done without any peculiar apparatus or expense, this characteristic of the alkalies will be imprinted on the mind, so as never to be effaced.

Let the student prepare a solution of the potash or pearlash of commerce, and when a little of this is poured into a wine-glass containing one of the common *blue* vegetable decoctions, the whole will immediately be changed to a *green*. If a few drops of diluted sulphuric acid be then added, the alkali will be saturated, and the colour will in some measure be restored; and by adding a very little more of the acid, the whole fluid will assume a beautiful crimson. Hot water poured on a few slices of the red cabbage will produce a blue decoction, very suitable for this experiment; or a strong infusion of the dried flowers of the red rose will answer the same purpose.

Although the alkalies, as has just been stated, convert the *blue* vegetable juices to a green, they produce a deep brown in the vegetable *yellows*. Thus, if a few drops of the solution of potash or of soda be added to an infusion of turmeric, the yellow will instantly be converted to a brown; and this new colour will be permanent, unless it be afterwards treated with an acid, which has the power of

restoring the original yellow; acids and alkalies, according to the predominance of either, having the property of alternately changing the hue of most vegetable colours. Hence the great use of this class of substances in the arts, especially in dyeing, and in the manufacture of several of the blue and green colours which are prepared for the painter.

The potash and pearlash of commerce were thought to be pure simple substances, until Dr. Black, in the year 1756, satisfactorily proved that they all contain a considerable portion of carbonic acid. The readiness with which lime deprives this alkali of its carbonic acid may be shown by the following very simple experiment. Pour a little clear solution of carbonate of potash into a wine-glass of transparent lime water; and though both liquors were perfectly limpid as the purest water while separate, they will instantly become turbid on mixture; for the lime, absorbing the carbonic acid from the alkali, will be converted to carbonate of lime or chalk, which, being an insoluble compound, will precipitate in a white powder.

The largest consumption of the alkalies is chiefly in the making of soap and glass. The principal part of the kelp that is prepared on the coasts of Wales, Scotland, and Ireland, is employed in the first of these compounds, besides some thousand tons of barilla annually imported frum the Continent, particularly from Spain, and from certain islands in the Mediterranean.

In the manufacture of soap, these rough alkalies

are bruised by means of a horse-mill; and when mixed with a portion of quick-lime sufficient to deprive them of their native carbonic acid, or fixed air as it was formerly called, they are put as lightly as possible into large cast-iron vats capable of holding from one to five or six tons each.

When these vats are thus charged, water is let in until it rises an inch or two above the surface of the materials, care being taken that it run on in a regular gentle stream, so as not to render the charge too solid, which would prevent the lye from running properly through it. The design of the water is to dissolve the alkali that is contained in the kelp, or barilla, and in this way to separate it from the various insoluble matters which these articles always contain.

The lime does not impart any of its own properties to the lye or the soap, as is often believed; it is employed merely to deprive the alkali of the carbonic acid which has just been noticed, and which would incapacitate the alkali for forming that intimate union with the oil or tallow which is required to render the whole into a perfect soap, soluble in water.

When the charge has stood thus covered with the fluid for twelve hours or more, the wooden plug near the bottom of the vat is loosened, and the alkaline lye which has been formed is suffered to run off gradually into a large iron receiver, fixed underneath and below the floor of the manufactory. This is called lye of the first running; and, being the

strongest, it is generally reserved for the last operations in the manufactory. The lixivium which has run from an adjoining but weaker vat, is now pumped upon that which has just been drained, and the whole is suffered to remain at rest as before. The liquor is thus pumped from beneath one vat upon the contents of another, and that again is replenished from the adjoining one, day after day, in regular succession, until the last of the series, which has frequently been covered with simple water, is thought to be entirely spent. When this is the case, the plugs are at once taken out of the whole row of vats, and the contents are suffered to drain for some time, preparatory to their being *cast*, as it is called, which is performed in the following manner:—The ashes of the spent vat are first thrown out as a refuse article; and when this vat is entirely empty, the contents of the adjoining one are thrown in, and so on to the end of the row, or to the beginning of the series, when the first vat, being then empty, is re-filled with a new charge of kelp or barilla. The plugs are now replaced, and the ashes in each vat are again covered with the weak lye from the receiver that is immediately underneath it. Thus the whole of the alkali and alkaline salts are dissolved, and the lixivium formed at a small expense of labour. By suffering the ashes thus to drain themselves entirely dry, and then casting them with large shovels into another vat, such parts as may have become conglomerated are broken, so that every thing which is soluble has a

chance of coming in contact with the fluid, and of being dissolved by it.

This narrative might perhaps have appeared with more propriety in an essay upon soap-making; but while treating expressly on the fixed alkalies, I was desirous of describing the method by which they can be rendered caustic at the least expense.

The alteration which is produced in the alkalies of commerce by the admixture of quick-lime is so manifest, and is attended with such important consequences, that the circumstance ought never to be forgotten by those who are engaged in any of the manufactories where large quantities of potash or soda are consumed: for in some, the quality of the manufactured article is much influenced by the state of the alkali; and in others, very great savings might be made by using caustic potash, or soda [12], in cases where the mild alkalies are now employed.

Many instances of these peculiar effects might be adduced: but I shall select one from the detersive property of the alkalies, that will sufficiently elucidate the practice which I am now attempting to enforce.

In scouring woollen yarn to free it from the oil which is combined with it in combing and spinning, it is no uncommon thing for the workmen to

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[12] A remarkable instance of the economy of using caustic instead of mild alkali may be seen in the Essay on Bleaching, in a subsequent part of this volume.

prepare a large boiler of lye, by dissolving American or Russian pearlash in water, by means of heat. When this liquor is hot, they immerse their brown yarn in it, and soon find it sufficiently freed from the oil and other filth that is attached to it. More is then immersed, but this takes a longer time to become clean; and the next parcel longer still; till at length it is so far spent as to have little or no effect upon the yarn, and is therefore suffered to run away to make room for a fresh lixiviation, although one half of the alkali in the former one is not consumed. Instead of proceeding in this way, let the workman mix a quantity of potash with one-fourth of its weight of fresh burnt quick-lime, (if pearlash be used, *one-half* its weight of lime should be taken,) put it into a vat, or into an iron pan, and then by the addition of water make a lixivium from it, as described above, and put only so much of this into the hot water as is necessary to scour that quantity of wool or yarn which is usually cleansed at once. Then let him add a few quarts more for the next parcel, and proceed in this way until the whole be finished, and he will find that any given quantity of work may be done with more expedition, and with less than half the alkali that is usually employed.

The lye made in the common mode operates very well at first, because a portion of the alkalies of commerce is generally in a caustic state; but as soon as this is saturated with the oil of the yarn, the remaining, and often the greater part, having no ef-

fect in the way they use it, is thrown away as useless, and is a total loss to the manufacturer. Many thousand pounds, I believe, are thus lost to the community annually, which might be saved by a general knowledge of this simple fact, *that alkalies will not combine with oleaginous matter, unless they are actually in a state of causticity.* The greater part of our American pearlash is combined with a very large portion of carbonic acid, and therefore it is not in a condition to combine with oil; but let it be divested of this acid, and it will not only form an intimate union with whatever oil or grease it comes in contact with, but it will render these impurities so completely soluble in water, that the whole will be as easily washed out from the yarn, and dissolved, as if it were sugar or salt.

Potash, as has before been mentioned, is prepared from the ashes of burnt wood, and is chiefly manufactured in those countries where there is an abundant supply of timber. It is observable, that in the middle of the last century it was not known how to make either potash or pearlash in any part of North America, equal in quality to that which had usually been imported from Russia. This was, however, at length effected by the persevering endeavours of a Mr. Thomas Stephens, who about the year 1753 received a grant from the Parliament of England for his encouragement [13]. The Russian

[13] See *The Method and plain Process for making Potash,* by Thomas Stephens, 4to, with plates. London.

method of making potash from large wood is fully described by Boerhaave in his *System of Chemistry*[14]: he has also given ample directions, in the same work[15], how various smaller vegetables may be managed in different circumstances, so as to be burnt for the production of potash[16]; and though there may be few cases in which his processes would answer, in this country, on a large scale, yet a perusal of his narrative will not fail to give the reader a very correct idea of the methods for obtaining this singular substance. More economical directions, however, and perhaps the best hitherto devised, may be seen in the *Annales de Chimie*[17].

It has generally been imagined that the alkali which is procured from vegetables is the creature of fire; but I know of one case (and there may be many others) in which vegetables are employed for the sake of the alkali they contain, without previously burning them. I refer to the operation of fulling woollen cloth.

When woollen cloth comes from the hands of the weaver, it is carried to the fulling mill, where

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[14] Dallowe's edition of Boerhaave's *Elements of Chemistry*, vol. i. page 443.

[15] *Ibid.* vol. ii. page 28—35.

[16] The Earl of Dundonald has proposed the cultivation of the common plant called *Tansy*, the *Tanacetum* of Linnæus, for the production of this alkali, asserting that it will yield more potash than can be procured from an equal weight of any other vegetable. The Finlanders obtain a green dye from this plant. See Dr. Withering's *Systematic Arrangement of British Plants*, vol. iii. page 872.

[17] Tom. xix. page 157—193.

it undergoes a long-continued beating by ponderous wooden hammers, which are moved with considerable force by a large water-wheel. By this treatment the cloth becomes considerably thicker, closer, and better; losing in its length and breadth exactly in proportion to its increased thickness. But it is rather a curious circumstance, that no woollen cloth will thicken by this operation until it be divested of the oil or grease which the wool had acquired in the process of combing and carding. To effect this, the following articles are made use of, viz. an earth which is principally brought from the county of Kent, called fullers'-earth, common hard soap, and a portion either of potash, or the crystals of soda.

In the county of York, however, where there are many hundreds of poor weavers who work in their own small cottages, and produce perhaps one piece of cloth only in a week or a fortnight, it is customary for them to take it to a public mill, with the necessary quantity of scouring materials, and there to superintend the operation, until the cloth is brought to that thickness which they conceive will occasion it to sell most to their advantage.

Now I understand it is no unusual thing for those poor people who wish to avoid the expense of buying alkalies, to send their wives and children to an

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[18] In the *Annales de Chimie* for the year 1791, there is a paper, by Bouvier, on the analysis of the Fuci. See vol. ix. page 83—95.

adjoining common to collect *fern*, which they throw into the mill with the piece, where its alkaline juices are expressed [18] and worked into the cloth; and that by this as good an effect is produced as if soda or potash had been employed. And in other cases, where soap and alkali have been used, and too small a quantity of these has been taken, so that the cloth will not thicken sufficiently, a small parcel of fern will occasion the operation to commence, and it will then go on as well as could be desired. Some of the lower class of weavers derive, as I have been told, considerable advantage from their knowledge of this very valuable plant [19].

Potash may also be procured from the ashes of burnt peat: but this is not a source from which it is generally obtained; nor do I know that the method is at all practised any where but in the Highlands of Scotland, where the poor inhabitants have learnt how to make the soap for their domestic uses, from the ashes of their own peat fires [20]. A letter from Glenesk in North Britain, on the manufacture of alkali from peat, was published some years ago in the *Tradesman's Magazine* [21].

Potash may likewise be obtained from saltpetre, by heating it sufficiently with charcoal, or any car-

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[19] See a paper by Monge on the Fulling of Woollen Cloth in the sixth volume of the *Annales de Chimie*, pages 300—311.

[20] A curious account of the method by which peat is conveyed from the tops of the mountains in Cumberland, by the neighbouring peasantry, is described in West's *Guide to the Lakes, in Cumberland, Westmoreland*, &c. page 96.

[21] The *Tradesman's or Commercial Magazine*, vol. ii. p. 517.

bonaceous matter that will decompose its acid. In this way one hundred weight of nitre will yield nearly half a hundred weight of pure potash; and whenever the relative prices of American potash and nitre will admit of it, the latter substance may be employed with profit for the production of this alkali. During our dispute with America, when the importations of pot- and pearl-ash were so small as to occasion a considerable advance on the customary prices of those articles, a large quantity of saltpetre was consumed in Great Britain for the above purpose; and for the *finer* kinds of flint glass, saltpetre may generally be substituted for potash with advantage.

Potash has been obtained in Germany, in pretty large quantities, from the pyroligneous acid, by pouring this acid on wood ashes, and then fluxing the whole in a furnace of brick or stone. The process is described by Glauber, in his *Miraculum Mundi*, with considerable minuteness [22]. Where saw-dust, straw, the tendrils of the hop, or bean-haums can be had in abundance, it might perhaps be advantageous to soak such materials in this acid, and then to burn and flux the whole into a saleable ash. But the oil should, if possible, be previously separated as much as possible from the pyroligneous acid.

Macquer relates, that in some parts of Germany potash is prepared from the same parcels of wood

[22] Glauber, *Chemical Works*, folio, page 188.

of which charcoal is made. A number of tubes made of plate iron or of copper, are so disposed in the pile of wood intended to be burnt into charcoal, that the acid, &c. is collected in reservoirs; and when the oil is separated the fluid is boiled in iron vessels, and the residuum is converted by calcination to an alkali [23].

Potash is a component part of pumice-stone, and of some other mineral productions. Professor Abilgaart found that this alkali formed also a constituent part of animal blood [24]; but it seldom occurs in other animal substances, except in very minute quantities.

Before I close this account it may be useful to remark, that the buyers of American potash generally prefer that which breaks red, which is, as I apprehend, a mere prejudice; for I have reason to think that this colour arises chiefly from the presence of sulphur, and perhaps oxide of iron, neither of which can be of any use where a good alkali is required. I have ascertained that some English makers of potash who are acquainted with this effect of sulphur, designedly add a portion of that substance to their ash, while it is in a state of fusion; and by taking a little from the melted mass after every addition of the sulphur, and suffering that to cool for examination, they are easily enabled to

[23] See the article "Alkali," in Macquer's *Chemical Dictionary*, vol. i.

[24] Parkinson's *Memoranda Chemica*, fourth edition, 1807, page 11.

bring the whole to that colour which will best suit the market.

Whenever this alkali is employed for nice purposes, the article called *pearlash* is generally preferred to potash. This is prepared by a long continued calcination of potash, at a low heat, whereby the sulphur and carbon which it contains are mostly burnt off. But as all the pearlash which comes from Russia and America contains a considerable proportion of neutral salts, it has long been, and still continues to be, our task to deprive it of these adulterations. And lately, several persons in various parts of this kingdom have established manufactories for preparing this alkali, and have produced considerable quantities, and comparatively in a state of great perfection, from various chemical residuums, which were formerly rejected as of no value.

In the neighbourhood of Birmingham there were formerly some very considerable manufactories of pot- and pearl-ash; and I have understood that the makers were enabled to sell both articles of as good quality and as cheap as the foreign.

Having thus fully treated on the history and origin of potash; on its various sources foreign and domestic; and on its nature and properties,—it will now be proper to give some account, however concise, of the several salts which are formed by its means, or which contain potash as one of its principal ingredients.

Acetate of potash, formerly called digestive salt of Sylvius.—It is in the form of plates or prismatic crystals. These dissolve in their own weight of water at 60°. The solution has an acrid saline taste. The salt is composed of

1 proportional of potash	=	45
1 ditto of acetic acid	=	48
		93

Ammonio-sulphate of potash.—This salt is formed by adding ammonia to the bi-sulphate of potash. The process is described by Link in Crell's *Annals* for 1796, vol. i. p. 26. It has a bitter taste like the common alkaline sulphates, and crystallizes in brilliant plates, which are not altered by exposure to the air. The salt consists of

Sulphate of potash	60
Sulphate of ammonia	40
	100

Antimoniate of potash.—This is a white powder possessing an acrid and metallic taste. It dissolves in boiling water, but is scarcely acted upon by cold water. According to Berzelius, it is composed of

Antimonic acid	79.2
Potash	20.8
	100.0

Antimonite of potash. In an Essay on Chemical Nomenclature, Berzelius states this salt to be composed of

Antimonious acid	76.6
Potash	23.4
	100.0

See Nicholson's *Journal*, vol. xxxv. p. 44. This salt is insoluble in cold, but soluble in boiling water.

Arseniate of potash.—This salt is formed by saturating arsenic acid with potash. It is deliquescent when exposed to the air, and is incapable of crystallization. It renders syrup of violets green, but has no effect on an infusion of turnsole.

Arsenite of potash.—This is a very soluble and incrystallizable salt. It is formed by boiling white arsenic in a solution of potash. This salt is the most important ingredient in Fowler's *tasteless ague drop.*

Aurate of potash.—This compound is introduced here, on the authority of Pelletier. This chemist has stated that pure potash is capable of dissolving the oxide of gold, and has named the compound aurate of potash.

Benzoate of potash.—This is a deliquescent salt, very soluble in water. If this salt be digested with benzoic acid, a bibenzoate will be produced in acicular and lamellar crystals, which require ten parts of cold water for their solution. See Bucholz, *Annales de Chimie*, vol. lxxxiv. page 311.

Bicarbonate of potash.—This salt is usually made by passing carbonic acid gas into a solution of potash in water, and evaporating the fluid to the point of crystallization. The crystals which separate are in the form of four-sided prisms, with dihedral summits. The dry salt consists of

2 proportionals of carbonic acid	=	41.4
1 ditto of potash	=	45.0
		86.4

When crystallized it consists of

Dry salt	86.4
Water	8.5
	94.9

Binarseniate of potash.—A salt formerly known by the name of the *arsenical neutral salt* of Macquer. It may be formed by adding arsenic acid in excess to potash, and evaporating the solution. The salt appears in quadrangular crystals, terminated by four-sided pyramids. It is much employed for the cure of agues. It is soluble in water; and, like the acids, it changes the blue juices of vegetables to a red. It is composed of

1 proportional of potash		=	45
2 ditto	of arsenic acid	=	133
			178

Binoxalate of potash is formed merely by dissolving the crystals of oxalate of potash in oxalic acid. It also exists ready formed in wood-sorrel, the *Oxalis acetosella* of Linnæus. When extracted it is sold under the improper name of *essential salt of lemons*. It is composed of

1 proportional of potash		=	45
2 ditto	of oxalic acid	=	71
			116

Biphosphate of potash.—This salt is easily formed by dissolving phosphate of potash in phosphoric acid, and evaporating the liquor to the point of crystallization. It crystallizes in small striated prisms

which are exceedingly soluble in water. The salt when dry has the specific gravity of 2.851. Hassenfratz, *Annales de Chimie*, tome xxviii. page 14.

Bisulphate of potash.—This salt, which is the *arcanum duplicatum* of the old chemists, may be formed by boiling the common sulphate of potash in sulphuric acid. It generally separates from its water of solution in needle-shaped crystals, which are soluble in two parts of water at 60°. This salt contains twice as much acid as the sulphate of potash. See Dr. Wollaston's paper on Super-salts and Sub-salts in the *Phil. Trans.* for 1808.

Bitartrate of potash is the common tartar of commerce. It exists in the juice of the grape, and when deposited on the sides of wine-casks is known by the name of *argol.* It is composed of

2 proportionals of acid	=	125
1 ditto of potash	=	45
		170

This salt requires 120 parts of water at 60°, or 30 parts at 212°, for its solution.

Boletate of potash.—The boletic acid is obtained from the juice of the *Boletus pseudo-igniarius.* The boletate of potash was formed by Braconnot: but all that he has said of it is, that it is very soluble in water, that it is not easily procured in crystals, and that other acids precipitate the boletic acid from it. See *Annales de Chimie*, tome lxxx. page 278.

Borate of potash.—This salt may be obtained either in a dry mass or crystallized. The crystals

are quadrangular prisms, unalterable by exposure to the air. The properties of this salt are little known. Berzelius attempted to ascertain its constituent parts, but without success. It may be procured by boiling boracic acid in a solution of potash.

Camphorate of potash may be made by saturating a solution of carbonate of potash with camphoric acid.—The salt crystallizes in regular hexagons, which are soluble in about 100 parts of water at 60°, or in 25 parts at 212°. It is soluble in alcohol, and the solution burns with an intense blue flame.

Carbonate of potash.—Large quantities of this salt are imported into this country under the names of potash and pearlash—articles very generally known. It is sometimes procured from nitre, and also from tartar. If these salts are submitted to a red heat with carbonaceous matter, their acids are separated thereby, and carbonate of potash is formed. It consists of

Carbonic acid	20.7
Potash	45.0
	65.7

Chlorate of potash, formerly called hyper-oxymuriate of potash, is made by passing a current of chlorine gas into a solution of potash, or carbonate of potash in water. It crystallizes in thin plates. When mixed with sulphur or phosphorus it explodes by trituration. See an account of many of these

experiments in the *Chemical Catechism.* This salt is composed of

1 proportional of chloric acid	=	71
1 ditto of potash	=	45
		116

Chromate of potash.—According to Vauquelin, there are two species of this salt, viz. the neutral chromate, and the bichromate. The former is of a pale lemon colour, the latter of an orange yellow colour. They both crystallize in small prisms.—*Annales de Chimie,* tome lxx. page 88.

Citrate of potash.—This salt has been already described in the Essay on Citric Acid, vol. i. p. 578.

Columbate of potash.—By boiling the columbic acid in a solution of potash, this salt is produced in white scales resembling those of boracic acid. When the mineral acids are added to a solution of this salt, the columbic acid is separated in the form of a white powder. See Hatchett, *Phil. Trans.* for 1802.

Ferrocyanate of potash is a salt much used in calico-printing.—It may be prepared by digesting Prussian blue in a hot solution of caustic potash. It is a triple salt, composed of hydrocyanic acid, potash, and oxide of iron. It crystallizes in fine cubic and tabular crystals of a bright yellow colour, and unchangeable in the air. See the Essay on Calico-printing, vol. i. page 295.

Ferrotartrate of potash may be made by digesting iron filings with tartar, in the proportion of one

part of iron with two parts of tartar, and then boiling the mass in a proper quantity of water to dissolve the triple salt which is formed by the process. In the old pharmacopœias this salt was known by the name of *Tartarized tincture of Mars*.

Fluate of potash.—This salt may be formed by the combination of pure potash with fluoric acid. Heat is given out on the mixture, and by subsequent evaporation the salt is obtained. It is deliquescent, and very soluble in water. It may be decomposed by the mere addition of sulphuric acid, which combines with the alkali and liberates the acid in the form of vapour.

Gallate of potash.—The properties of this salt are not known.

Hydrate of potash.—The fixed alkalies contain a considerable portion of water, even after they have undergone a red-heat. Hence the alkalies of commerce are always in the state of hydrates. The hydrate of potash consists of

1 proportional of potash	=	45.0
1 ditto of water	=	8.5
		53.5

Hydriodate of potash is formed by dissolving carbonate of potash in hydriodic acid. Dr. Thomson has stated the constituents of the salt to be,

Hydriodic acid	100.00
Potash	38.09
	138.09

See Gay-Lussac, *Annales de Chimie*, xci. p. 55.

Hydroguretted sulphuret of potash.—This salt may be formed by mixing flour of sulphur with a solution of hydro-sulphuret of potash, and digesting the mixture in a gentle heat. Thus an additional portion of sulphur will be dissolved, and an hydroguretted sulphuret of potash formed, which is a salt of a deep yellow colour, with a very pungent and bitter taste.

Hydrosulphuret of potash may be produced by saturating potash with sulphuretted hydrogen. The fluid will be colourless and transparent, and on evaporation will yield crystals not unlike those of sulphate of soda. See Vauquelin, *Annales de Chimie*, tome xlii. page 40.

Hyperoxymuriate of potash.—This salt is the same as the one already described under the more modern name of Chlorate of potash.

Hypophosphite of potash.—This is a deliquescent salt, very soluble either in water or alcohol. When submitted to heat, phosphorus and phosphuretted hydrogen escape, and the salt is converted to phosphate of potash. See Dulong, *Annales de Chimie et Phys.* tome ii. page 142.

Hyposulphite of potash.—This salt is prepared by treating hydrosulphuret of potash with liquid sulphurous acid, and evaporating the solution to the point of crystallization. On cooling, needle-formed crystals are produced, which have a bitter taste, and deliquesce when exposed to the atmosphere.

Iodate of potash.—This is a white salt in very minute crystals. It is not altered by the air; but if

heated to redness, oxygen gas is given off, and iodide of potassium is produced. One hundred parts of water at 14¼° centr., or 57½° of Fahrenheit, will dissolve 7.43 parts of this salt. Gay-Lussac, *Annales de Chimie*, tome xci. page 74.

Lactate of potash may be obtained by saturating carbonate of potash with lactate of lime. The salt has the appearance, when the water is abstracted by evaporation, of a yellowish brown gum of a soft consistence. It is soluble in heated alcohol.

Malate of potash is a deliquescent salt, and so extremely soluble in water as to be incapable of crystallizing.

Meconiate of potash forms itself in four-sided tables, which are soluble in two parts of water at 60°, and composed of

Potash	60
Meconic acid	27
Water	13
	100

See Brande's *Manual*, vol. iii. page 71.

Mellate of potash is a salt which crystallizes in elongated prisms. By a further addition of the acid, a supermellate may be formed. Vauquelin, *Annales de Chimie*, tome xxxvi. page 209.

Molybdate of potash may be formed by digesting molybdic acid in a solution of potash. The salt crystallizes in small rhomboids, running into one another. These are soluble in hot water: but the molybdic acid may be precipitated therefrom by the

addition of sulphuric or muriatic acid. See *Annales de Chimie*, tome viii. page 106.

Muriate of potash.—This salt is in fact a chloride of potassium, consisting of

Potassium	37.5
Chlorine	33.5
	71.0

It crystallizes in cubes which deliquesce rapidly in the atmosphere. It was formerly called Salt of Sylvius, and Regenerated sea-salt. In philosophical chemistry it is very much employed to produce artificial cold.

Nitrate of potash, or what is usually called Saltpetre, is produced naturally in some particular districts in all hot countries: but that which is consumed here is chiefly brought from the East Indies. It crystallizes in hexagonal prisms. One hundred parts of water at 60° dissolve fourteen parts of this salt, and boiling water dissolves more than its own weight. This salt, according to Dr. Wollaston, is composed of

Nitric acid	53.54
Potash	46.46
	100.00

Nitrite of potash is a salt which was first observed by Scheele. His process for preparing it is to fill a large crucible with nitre, and keep it in a red-heat for half an hour. During this time a portion of oxygen escapes, and what remains in the crucible is *nitrite* of potash, a salt which will deliquesce when exposed to the action of the air.

Oxalate of potash.—This salt is formed by dissolving potash in a solution of oxalic acid. It crystallizes in flat rhomboids, soluble in three parts of water at 60°. It is composed of

1 proportional of oxalic acid	=	35.5
1 ditto of potash	=	45.0
		80.5

Oxychlorate of potash, which is a very insoluble salt, crystallizes in elongated octoëdrons. It consists of

1 proportional of oxychloric acid	=	86
1 ditto of potash	=	45

It is unalterable in the air, and possesses no bleaching properties whatever.

Oxymuriate of potash.—The same as the salt which Chenevix named hyper-oxymuriate, and which has already been described under the name of *Chlorate of potash,* which see.

Phosphate of potash.—This salt may be produced by adding carbonate of potash to hot phosphoric acid until the point of saturation be attained. If the solution be much concentrated and then suffered to cool gradually, small prismatic crystals of phosphate of potash will be obtained, consisting of

1 proportional of potash	=	45
1 ditto of phosphoric acid	=	26
		71

Phosphite of potash.—This is a deliquescent salt, incapable of crystallization. Its properties, or even its component parts, are not yet known.

Prussiate of potash.—This salt has been already described under the name of *Ferrocyanate of potash.* See page 26 of this volume.

Quadroxalate of potash was discovered by Dr. Wollaston. When the Binoxalate of Potash mentioned at page 23 is digested in dilute nitric or muriatic acid, a part of the alkali is taken up, and a salt remains consisting of four times as much oxalic acid as exists in oxalate of potash. It is formed of

4 proportionals of oxalic acid	35.5 × 4	=	142
1 ditto of potash		=	45

Saclactate of potash.—Scheele has treated on this salt in his Essay on the Sugar of Milk. He describes the salt to be in small crystals soluble in eight times their weight of water at 212°.

Silicate of potash was known to the old chemists. It may be prepared by fusing three parts of good potash with one part of ground silica, both calculated by weight. The resulting compound forms a kind of glass on cooling which is soluble in water. The solution thus formed is called *liquor silicum.*

Sorbate of potash.—The sorbic acid was discovered in 1815 by Mr. Donovan in the juice of the berries of the mountain ash. United with potash this acid forms two distinct salts, viz. the *sorbate* of potash which is incrystallizable, and the *bisorbate,* which gives permanent crystals soluble in water, but insoluble in alcohol.

Subcarbonate of potash.—This salt is well known

under the names of potash, pearlash, and salt of tartar. It consists of one proportional of potash = 45 + one of carbonic acid = 20.7.

Suberate of potash is best prepared by digesting suberic acid with a solution of crystallized carbonate of potash. The salt crystallizes in prisms, and these are very soluble in water.—*Annales de Chimie*, tome xxiii. page 52.

Subphosphate of potash.—This salt has been formed by fusing pure potash, with the phosphate of this alkali, in a platinum crucible. It is either a white solid, or a white powder, according to the mode of its preparation. Saussure jun. determined it to consist of

Phosphoric acid	35
Potash	65
	100

Succinate of potash is a salt which crystallizes in small prisms, deliquesces in the air, and is very soluble in water. Its taste is saline and bitter.

Sulphate of potash.—This salt, which is the same as the *sal de duobus* of the old chemists, is produced as a residuum in large quantities by the makers of nitric acid, and is sold under the name of *sal enixum*. It has a saline bitter taste, and when dissolved in water crystallizes for the most part in short six-sided prisms, terminated by hexangular pyramids. It is composed of 100 sulphuric acid + 112.35 potash = about 47 acid and 53 base. See *Annales de Chimie*, tome lxxvii. page 84.

Sulphite of potash.—This salt, which was formerly known by the name of the sulphurous salt of Stahl, may be formed by passing sulphurous acid gas into a saturated solution of very pure carbonate of potash, until the effervescence entirely ceases. The solution becomes warm during the combination, and the salt crystallizes on cooling in the form of rhomboidal plates. These by exposure to the air are converted to sulphate of potash. See a memoir by Fourcroy and Vauquelin in Nicholson's *Journal*, 4to, vol. i. page 317.

Sulphuret of potassium is formed by the fusion of a mixture of sulphur and potash. This was formerly called liver of sulphur, and consists of

1 proportional of potassium	=	37.5
1 ditto of sulphur	=	15.0
		52.5

Superoxalate of potash.—This salt has already been described under the name of binoxalate of potash, which see.

Superphosphate of potash.—The same as the biphosphate described at page 23 of this volume.

Supersulphate of potash.—This salt is the same as the one already described, at page 24, under the name of bisulphate of potash.

Supertartrate of potash is the same as the bitartrate mentioned at page 24, and commonly known by the name of cream of tartar.

Tartrate of potash is formed by adding a quantity of potash to the last-named salt, sufficient to

saturate the excess of acid. It is called soluble tartar, and is used in medicine as an aperient. It consists of

1 proportional of acid	=	62.5
1 ditto of potash	=	45.0
		107.5

Tartrate of potash and antimony.—This is that important combination usually known under the name of emetic tartar. It is a white salt, requiring 14 times its weight of cold water, or two parts of water at 212°, for its solution. It is composed of

2 proportionals of tartaric acid		$62.5 \times 2 = 125$
2 ditto	of protoxide of antimony	$52.5 \times 2 = 105$
1 ditto	of potash	= 45
		275

Tartrate of potash and soda, or Rochelle salt, is usually prepared by adding the crystals of carbonate of soda to the supertartrate of potash, until the excess of tartaric acid is saturated. It is then purified by repeated crystallizations, and appears in irregular prismatic crystals. According to Vauquelin, it consists of

Tartrate of potash	54
Tartrate of soda	46
	100

Tellurate of potash.—If oxide of tellurium be mixed with nitre, and the mixture be exposed to heat, the nitre first melts without acting on the oxide; but at the temperature in which the oxide be-

gins to liquefy, it decomposes the nitre with a violent effervescence, the nitric acid is driven off, and the oxide dissolves in the potash. The mass when cold very much resembles an enamel. It dissolves in boiling water, and the solution on cooling deposits an imperfectly crystallized white powder. This is tellurate of potash. It has a slight metallic taste, and acts feebly as an alkali on vegetable blues. —Thomson, vol. ii. page 665. Berzelius, Nicholson's *Journal*, vol. xxxvi. page 130.

Triple prussiate of potash.—This is the same as the ferrocyanate of potash already described.

Tungstate of potash is a salt which may be prepared by dissolving the oxide of tungsten in a strong solution of carbonate of potash. When this saturated solution is concentrated by evaporation a white powder falls down, which is the tungstate of potash. This salt deliquesces when exposed to the air, and consequently is very soluble in water.

Urate of potash.—This salt is stated by Dr. Thomson to be a white powder nearly similar to uric acid in appearance and solubility. It is also soluble in a lye of caustic potash.

Zumate of potash.—Zumic acid is obtained by a peculiar process from rice. It was first described by Braconnot, but the name which it now bears was given by Dr. Thomson. The zumate of potash is a deliquescent salt, incapable of crystallization, and soluble in alcohol.—*Annales de Chimie*, tome lxxxvi. page 84.

The other alkali of which we have to treat, is SODA, which is also known by the names of natron, barilla, mineral alkali, and fossil alkali. This substance is met with in abundance, and even used for various purposes, in China, Persia, in the environs of Smyrna and Tripoli [25], and in general all over the East, as well as on the northern coast of Africa, in Hungary, and Siberia. It likewise occurs in the state of carbonate of soda in many of the mineral waters of Germany [26].

Native soda is also found in large quantities, on the surface of the ground, in the plains of the Delta in Egypt, from whence it is brought to this country under the name of natron. It occurs likewise in the same state in the East Indies, and in the islands of Sicily and Teneriff. These islands furnish us also with a large quantity of soda, in the form of barilla, which is chiefly consumed in the soap trade, as already mentioned.

Barilla is likewise imported in very considerable quantities from Spain. This is made by the incineration of the *salsola soda*, a marine plant, which is so highly valued by the Spaniards, that the exportation of the seed is, by the law of the country, punishable with death. It is cultivated with great

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[25] See Hopson's Translation of Weigleb's *System of Chemistry*, page 193.

[26] M. Bagge, Swedish Consul at Tripoli, has published a particular account of the way in which native soda is found. See *Memoirs of the Academy of Stockholm*, tom. xxxiv. page 140. An account of the manner of obtaining it in China may be seen in the same work, tom. xxxiii. page 170.

care in the neighbourhood of Alicant and Carthagena, for the production of barilla; but that of Alicant is generally the most esteemed.

And here we must not omit to mention the manufacture of kelp, upon our own shores, and which is so considerable as to furnish the English market with many thousand tons of soda annually. The manufacture of this article was introduced into the Highlands of Scotland about the year 1730, by a gentleman of the name of MacLeod, who brought the art of cultivating it from Ireland. From the year 1740 to 1760, the manufactured kelp was generally sold at about 45*s.* per ton. Since then it has gradually advanced in price to 11*l.* or 12*l.* per ton.

Since the manufacture of kelp has been introduced into the Orkneys, small farms of forty pounds a year have risen to 300*l.* a year[27]; and "it is said that Lord MacDonald of the Isles realizes ten thousand pounds a year from his kelp shores alone, which his ancestors looked upon as of no value whatever. So much indeed are the proprietors of the sea-coast now impressed with the value and importance of the kelp manufacture, that they have found the means of producing it on the very sands. They place stones within flood-mark of the sea, which are soon covered with *ware*, as it is commonly called, and which is the vegetable substance from which kelp is made[28]."

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[27] Jameson's *Account of the Scottish Isles*, vol. ii. page 244.
[28] *Tradesman's Magazine.*

The British kelp is prepared by the burning of various plants of the genus of the *salsola* of Linnæus, (the common sea-wrack,) and similar to the *salsola soda* of the Spaniards; but the article which is procured from these plants is much inferior to barilla, inasmuch as it contains a large portion of neutral salts, a quantity of potash, and a much larger proportion of carbonaceous matter than is generally found in the former article[29].

In making either barilla or kelp, the weed is collected into heaps to ferment; it is then spread to dry in the air, and is afterwards burnt to ashes in ovens made with brick or stone, and built within the ground. By increasing the heat, the alkali in the ashes melts, and calcines the whole into one solid mass. When cold, it is broken up with iron bars into large ponderous masses, and in that state it is sent to market. The best account that I have seen of the manufacture of kelp is in Jameson's "*Mineralogy of the Scottish Isles*[30];" and in a paper by Mr. Beaton, which has been printed in *The Repertory of Arts*[31], from the *Prize Essays of the Highland Society of Scotland*[32]. Some further information may be obtained from Dr. An-

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[29] For a new explanation of an important difference between kelp and barilla, see a note under the article "*Alkalies*," in *The Chemical Catechism*, tenth edition, page 130, 131.

[30] Quarto, London, vol. ii. page 244.

[31] Vol. xii. page 243.

[32] An account of the kilns which are generally made use of for the manufacture of kelp, may be seen in the *Transactions of the Highland Society*, vol. i. page 24, &c.

derson's *Account of the Hebrides*; and from my own "Prize Essay on Kelp and Barilla" in the fifth volume of the *Transactions of the Highland Society of Scotland*, pages 65—122.

Here it will be proper to endeavour to correct an error which the purchasers of kelp and barilla in general labour under. It often happens that a lot of kelp or barilla lies a long time in the merchant's warehouse, until by the action of the air the greater part of the large lumps fall into pieces, which gives the whole a very different appearance from what it had at the time of importation.

Whenever I have had occasion to examine such a parcel in company with the buyers of the article, I have never failed to observe the great depreciation in price which such a lot always suffers from this circumstance. I have seen persons, who would not buy it at any price; and it is no uncommon thing for people to refuse a very valuable parcel of this kind, when it might have been bought considerably below its real worth.

Had these men been chemists, they would have known that the fixed alkalies are imperishable, and that no length of time can injure them, provided they are kept in a situation where they cannot be dissolved by moisture, or washed away by the rain.

In bargaining for such alkalies, a chemist would calculate how much carbonic acid and water have been absorbed since their importation; and then, having made that deduction, he would know that

the commodity is worth as much to him as if he had taken it home immediately on its being landed.

For some purposes, indeed, alkalies improve by age. It is well known that in the crude state they contain a portion of alkaline sulphuret, which is decomposed by the absorption of carbonic acid, and the sulphur separated; so that, whenever such barilla or kelp is lixiviated in its mild or carbonated state, it will furnish a much purer lye than can be had even from that which purchasers in general buy with avidity.

It has long been a desideratum with the soap-makers and other purchasers of kelp and barilla, who happen to have no knowledge of chemistry, to find a method of ascertaining the exact portion of alkali in any sample which may come under their examination; and as no accurate directions have been published, at least that I have seen, I shall here give a detail of the mode which I have followed for several years, in many hundreds of cases, and which has in no instance deceived me. In preparing for the analysis, it will be necessary to attend to the following directions.

In the first place, procure a pair of good small scales with a set of decimal weights, from one grain to a thousand grains [33]; a graduated drachm measure, also a two-ounce measure, both of glass; a

[33] These weights may now be had at any of the scale-makers in London. The set, in a neat mahogany box, will cost about 20s.

strong phial that will pour well; some litmus-paper of both kinds, viz. blue and red; a bottle of the solution of muriate of platinum; and some sulphuric acid diluted with pure water until it be reduced, when cold, to the specific gravity of 1,100.

Some respectable chemical writers, in describing the method of analysing alkalies, have directed us to take a given portion of the sulphuric acid of commerce, and dilute it with a given portion of water; but as the sulphuric acid of the shops varies very much in strength, it is impossible by this method to attain accurate results. The only method that can be depended upon, is that of reducing the acid to some certain specific gravity. That which I have found the most convenient, is the specific gravity of 1,100, and this is generally attained by mixing about six parts of water with one part of the best oil of vitriol of commerce, both to be estimated by weight and not by measure.

When any parcel of kelp or barilla is to be examined, it will be proper to select as fair an average sample as possible. This can only be done by taking several lumps from different parts of the heap, by breaking a small piece from each of these lumps, and mixing them with a fair proportion of the small which may belong to the lot. The sample should then be pulverized in an iron mortar, that the whole may be more completely mixed; and a small quantity of this, say about an ounce, should be returned into the mortar and ground to an impalpable powder, that the alkali may be dis-

solved out of it with greater ease and certainty. Things being thus prepared, the analysis is to be proceeded with in the following manner:

Take the weight of one hundred grains of the alkaline powder, put it into a convenient vessel, and pour over it a two-ounce measure of pure water. Stir the mixture with a piece of glass, repeating it now and then during the space of a few hours. When the insoluble matter has been suffered to subside, pour the supernatant liquor upon a paper filter, and add another measure of water to the residuum, which should be well stirred once or twice, and then be suffered to remain as before. It is necessary to attend to the circumstance of filtrating the solution: otherwise there might be a portion of lime or carbonate of lime in it, which would absorb part of the acid employed in the analysis, and occasion an inaccurate result. When this lixivium has been thus filtrated, the residuum itself should be put upon the filter, and small portions of water poured over it occasionally, until the water passes through it devoid of taste and colour.

These solutions are now to be mixed, and put into a convenient vessel, in which they should boil until the whole is reduced to about two or three ounces, when it will be sufficiently concentrated for the examination, which should be conducted in the following manner:

Take about two ounces of diluted sulphuric acid, as above mentioned, of the specific gravity of 1,100; and having weighed it accurately, together with the

phial, note down the united weight of both in grains. Then pour a portion of the acid very gradually into the alkaline solution, and stir it well with a glass rod, till the effervescence occasioned by the escape of the carbonic acid has ceased.

A slip of the reddened litmus-paper should now be dipped into the solution; and if this becomes blue, it shows that the liquid still contains alkali, and that more acid must be added. In the beginning I generally put one drachm in measure of the diluted acid to the lixivium after every trial with the test paper. This, however, must now be done cautiously, taking care to stir the mixture well after every addition of the acid.

When the effervescence becomes less, and the test paper receives only a slight blue tinge by immersion in the lixivium, the acid should be added still more gradually, and by a very few drops at a time, that no more acid may be employed than is absolutely requisite for the complete saturation of the alkali; which may be known by the cessation of the effervescence, the unchangeable appearance of the test paper on immersion, and the separation of the sulphur which was held in solution by the alkali, and which separates when the alkali becomes saturated with an acid.

The alkali having been in this way rendered neutral, the remainder of the acid with its phial is to be weighed again, to ascertain how much of the diluted sulphuric acid has been consumed; and this will show the precise quantity of real alkali which is

contained in the sample under examination, when it is known how much acid an alkali in a state of purity is capable of taking up.

In order to provide a scale for calculating this, I took 100 grains of dry potash purified by means of alcohol; and having treated it with the diluted sulphuric acid of the specific gravity of 1,100, I found that it required exactly 520 grains of the acid to saturate it. In like manner I treated pure soda: but 100 grains of this alkali require 812 grains of acid of the same strength for its saturation.

These results being considered as the basis, it is easy, by the rule of proportion, to calculate how much real alkali there is in any sample of kelp, natron, or barilla, by the weight of acid required to saturate it.

But as the two alkalies combine with different portions of acid, the analysis cannot be accurate unless it be ascertained whether the alkali in the sample be soda only, or a mixture of soda and potash; and, if it be of the latter kind, in what relative proportions these alkalies exist.

The most useful test in this case is the liquid muriate of platinum, made by dissolving the crystals of that salt in pure water; for, if a drop of this reagent be added to a small quantity of any alkaline solution, a yellow precipitate, which is a triple compound of potash, oxide of platinum and muriatic acid, will appear if the alkali contain potash; whereas, if it be a solution of soda only, no precipitate will occur. If the alkali under examination should

contain *muriate of potash*, (which, however, very rarely occurs,) this would likewise produce a precipitate, and might occasion deception; for the muriate of platinum detects all the *salts* of potash as well as *pure* potash. Should a sample be suspected to contain this salt, a small portion of the lixivium might be supersaturated with sulphuric acid, by which means the muriatic acid would be driven off and easily detected by its peculiar smell, or by presenting ammoniacal gas; and the potash, in the form of sulphate, would be separated by its crystallizing before the sulphate of soda.

There are several other methods by which the fixed alkalies may be distinguished from each other. These are all described in *The Chemical Catechism*, tenth edition, page 127, &c. The use of muriate of platinum has often been stated to be a new method of detecting potash; but in justice to the memory of Margraff it ought to be known, that he pointed it out for this especial purpose more than seventy years ago [34].

Soda in its pure state is very similar in the causticity of taste to that of potash; though in its usual condition it does not so readily absorb water from the atmosphere; on the contrary, its crystals effloresce, and entirely lose their water of crystallization by such exposure. If, however, pure soda be rendered very dry and then moistened with water, it will absorb the water with avidity, and heat will be given

[34] See Macquer's *Chemical Dictionary*, the article *Alkali*.

out during this absorption, owing to the water becoming actually solidified by the alkali.

Although soda is so analogous to potash in many of its habitudes, that it can only on certain occasions be distinguished by chemical tests, yet the action of these two alkalies in some manufactures, and the combinations they form, are so dissimilar, that we are under the necessity of considering them to be perfectly distinct bodies.

The most remarkable difference in the effects of these alkalies, when employed in manufacturing processes, is in the articles of soap and glass. In that of glass, the mineral alkali more easily combines with the silica; consequently the frit is formed with greater facility and certainty. It has also been said that soda produces a glass of greater hardness: but of this there is some doubt.

In the manufacture of common hard soap, soda is an essential ingredient. Pure potash will also combine with oil or tallow, and form a complete soap; and it is by this alkali that all the *soft* soap is made which is prepared in Great Britain. But if more than a certain proportion of potash be used in the manufacture of *hard* soap, although the soap might have sufficient consistence, and appear perfectly good when finished, its character would be entirely changed the first day of its exposure to the action of the air in damp weather; for it would then become soft, flexuous, and unsaleable. Great losses were formerly sustained by many manufacturers of soap, from their ignorance of this circumstance.

However, if this imperfect soap be dissolved in hot water, and brought to a boiling heat, and while boiling, a sufficient portion of common salt be added, the moment these substances come in contact with each other, the potash will quit the tallow to unite with the muriatic acid of the salt, and the soda will then supply its place, and combine with the tallow, so as to form a hard, firm and saleable soap.

Having already given some account of the salts of potash, it will now be proper to notice the principal salts which have been formed by means of soda. These may frequently be known from the former by their greater degree of solubility in water, and by their containing much water of crystallization, though to this there are some exceptions. They may also be distinguished from the salts of potash by their yielding no precipitate when treated with tartaric acid or with a solution of muriate of platinum.

Acetate of soda.—This salt was known in the old pharmacopœias by the name of *crystallized foliated earth.* It crystallizes in prisms similar to sulphate of soda; but these cannot be obtained unless the solution contains an excess of soda. It consists of 29.5 soda+48 acetic acid.

Arseniate of soda.—This salt differs from arseniate of potash, inasmuch as it crystallizes in six-sided prisms; whereas the latter is incapable of crystallization. If there be, however, an excess of acid in the solution, the arseniate of soda will not crystallize.

Arsenite of soda.—This, like the arsenite of potash, is incapable crystallization, being a thick yellow liquid, with an odour that is peculiarly nauseous. This salt is decomposable by heat, and the arsenious acid escapes in vapour. According to Professor Brande[35], the arsenite of soda is a compound of

1 proportional of arsenious acid	=	54
1 ditto of soda	=	32
		86

Benzoate of soda.—Unlike its correspondent salt of potash, which is deliquescent, this salt effloresces in the atmosphere, but its taste is similar, and it is also very soluble in water. The crystals likewise are considerably larger than the crystals of benzoate of potash.

Bicarbonate of soda.—This, like the bicarbonate of potash, may be prepared by passing a stream of carbonic acid gas into a solution of the soda of commerce. This process produces a solid mass of the salt, which when dried is usually pulverized for sale. If the bicarbonate of soda be exposed to a red-heat, it will lose exactly one-half of its carbonic acid, and thereby be reduced to common carbonate[36]. It may be observed, that this salt is found native in some parts of Africa in considerable quantities, and has been imported into this country, and sold under the name of *trona*. There is a process in the London Pharmacopœia for preparing this bicarbonate,

[35] Table of prime equivalent numbers, page 12.
[36] Wollaston, *Philos. Trans.* 1808.

by treating the carbonate of soda with carbonate of ammonia, which see.

Borate of soda is readily formed by saturating common borax with the boracic acid; borax itself being a sub-borate of soda. According to Bergman, two pounds of borax will require one pound of boracic acid for its saturation.

Camphorate of soda is similar to camphorate of potash in most of its properties, and may be formed in the same manner. Its crystals are in irregular forms, but they may be obtained very white and transparent. If submitted to heat, the acid burns with a beautiful blue flame at the first, and afterwards with one of a purple hue. In the year 1798 Mons. Bouillon Lagrange read an Essay, before the Philomathique Society of Paris, on the properties of the camphoric salts, and the method of preparing them [37].

Carbonate of soda. This salt, which is employed in large quantities in the manufactures of the country, is usually produced from three distinct sources, viz. from the barilla of Spain and Sicily, from the kelp which is made on our own shores, and from a native production which is brought from Egypt under the name of natron. It crystallizes in octohedrons, with a rhombic base, forming a solid with ten faces. The dry salt consists of

Soda	29.5
Carbonic acid	20.7
	50.2

[37] *Annales de Chimie*, xxvii. pages 19—41.

The crystallized salt consists of

Carbonate of soda	50.2
7 waters . . . . . 8.5 × 7 =	59.5
	109.7

Chromate of soda is a crystallizable salt of an orange colour. If a solution of chromate of soda be added to a solution of lead, copper, iron, mercury, or silver, it forms an insoluble precipitate, varying in colour according to the nature of the metallic solution into which it is poured. In the solutions of zinc, tin, and some other metals it forms no precipitate[38].

Citrate of soda.—This salt agrees in several of its properties with citrate of potash. It crystallizes in hexahedral tables, and is soluble in two parts of water at 56°, and effloresces when exposed to the air. It is considered by Vauquelin to be composed of

Citric acid	60.7
Soda	39.3
	100.0

Mr. Brande makes it to consist of

1 proportional of citric acid =	55.5
1 ditto of soda =	29.5
	85.0

Fluate of soda is formed by pouring a solution of pure soda into fluoric acid. The salt crystallizes on cooling. It has less taste than fluate of potash,

[38] See John, *Annals of Philosophy*, vol. iv. page 425.

and is not altered, like that salt, by exposure to the air.

Hydrate of soda is a compound of caustic soda and water. Though this alkali be purified as much as possible by lime and alcohol, and afterwards by fusion, it will still contain a portion of water. It consists of 29.5 protoxide of sodium + 8.5 water.

Hydrosulphuret of soda crystallizes in four-sided prisms, terminated by quadrangular pyramids. Its taste is intensely bitter, though the crystals are transparent and colourless. It is very soluble in water, and deliquesces in the air, during which process the solution acquires a green colour.

For some account of the formation of this salt, see the article sulphuret of soda.

Iodate of soda.—This salt has been formed and examined by Gay Lussac. It may be made by dissolving iodine in a solution of pure soda. It forms itself in small prismatic crystals.—*Annales de Chimie*, tome xci.

Lactate of soda.—This salt is very similar to lactate of potash. It has been examined by Berzelius, who thinks the two salts can only be distinguished by analysis.

Malate of soda.—This salt is uncrystallizable, very soluble in water, and deliquescent in the atmosphere.

Molybdate of soda agrees with molybdate of potash in many of its properties; but it is more soluble in water, and affords transparent crystals, which are unalterable by exposure to the atmosphere.

Muriate of soda is one of the most abundant salts in nature. It is the chief ingredient in sea-water, it abounds in salt springs in most parts of the world, and is found in immense masses in the county of Chester in the form of rock-salt. A valuable paper by Dr. Henry on the various kinds of common salt, will be found in the *Philosophical Transactions* for 1810, page 89, &c.

When pure it consists of 22 sodium + 33.5 chlorine.

Nitrate of soda is the cubic nitre of the old chemists. It forms itself in rhombic crystals, which require three parts of water at 60° for their solution. It has in a slight degree the property of deliquescence, and is soluble in less than its own weight of water at 212°. It is a compound of

Soda	29.5
Nitric acid	50.5
	80.

Dr. Lewis has treated at length on the nature of this salt[39].

Oxalate of soda is a salt which appears in small crystals like grains of sand. This salt dissolves in cold water with difficulty, but is perfectly soluble in hot water. Its taste is cooling and bitter, and it falls to powder when submitted for some time to a

[39] *Philosophical Commerce of the Arts*, pages 642—646.

gentle heat. According to Professor Brande [40], it consists of

1 proportional of oxalic acid	=	35.5
1 ditto of soda	=	29.5
		65.0

Vogel of Bayreuth makes this salt to consist of

Oxalic acid	54.77
Soda	45.23
	100.00

Phosphate of soda.—This is the *sal perlatum* of the old chemists. It possesses a very mild saline taste, and on this account was introduced into the practice of medicine by Dr. George Pearson. It consists of

Soda	29.5
Phosphoric acid	26.0
	55.5

When crystallized, the proportions are very different, as the crystals contain more than half their weight of water. These are often used in the arts as a metallic flux.

Phosphite of soda.—The properties of this salt are not much known. It has, however, been seen that the hypophosphite of soda is very soluble both in water and in alcohol. *Annales de Chimie et Phys.* tome ii. page 142.

[40] *Manual of Chemistry*, vol. iii. page 348.

Silicate of soda.—This salt may be formed in the same way as silicate of potash, with the substitution of the mineral for the vegetable alkali. Glass is a supersilicate, containing a considerable excess either of potash or soda. See the Essay on the Manufacture of Glass, in this volume.

Subborate of soda is brought from the East Indies in a very impure state, and sold under the name of tincal. Formerly none but the Dutch were capable of purifying it; but now this is well done both in France and in England, and when purified is called borax. The crystals are irregular hexangular prisms, which are slightly efflorescent. These, according to Bergman, are composed of

Boracic acid	34
Soda	17
Water	49
	100

Boracic acid is usually procured from this salt by the affusion of sulphuric acid; but its chief consumption is as a flux, and by the braziers for solder.

Suberate of soda.—This salt differs from the suberate of potash chiefly in the circumstance of its being incapable of crystallization; whereas suberate of potash crystallizes in prisms. The best account we have of these salts will be found in a copious extract, in the *Annales de Chimie*, from a memoir on cork, and on the combinations of its acid, read to the Institute of Paris by Bouillon La Grange [41].

[41] *Annales de Chimie*, tome xxiii. pages 42—62.

Succinate of soda.—This salt differs in several respects from succinate of potash. It crystallizes in hard transparent four-sided and hexagonal prisms, which are unchangeable in the air; whereas the succinate of potash is extremely soluble, is crystallized with difficulty, and the salt, which is in the form of very small prisms, readily deliquesces in the atmosphere.

Sulphate of soda.—This is the *sal mirabile* of the old chemists, and has been long known in this country under the name of *Glauber's salt*. It usually crystallizes in large four-sided prisms, hard and transparent; but they effloresce when exposed long to the atmosphere, and fall into powder. Sulphate of soda is produced in considerable quantities by the makers of muriatic acid. It is composed of

1 proportional of acid	=	37.5
1 ditto of soda	=	29.5
		67.0

or,

Sulphuric acid	56
Soda	44
	100

When crystallized it consists of

Dry sulphate of soda	67
Water	85
	152

Sulphite of soda. This is a crystallizable salt, not quite so soluble as the sulphate of soda. It consists of

1 proportional of sulphurous acid	=	30.0
1 ditto of soda	=	29.5
		59.5

The crystals are composed of one proportional of the salt and eight proportionals of water[42].

Sulphuret of soda.—When sulphur and soda are fused together, a red compound is formed, whose taste is bitter and otherwise disagreeable. This is sulphuret of soda. For an account of its nature and properties, see Vauquelin, *Annales de Chimie*, tome xli. page 190. When this sulphuret, which is very deliquescent, is dissolved in water, it produces a yellow solution of hydrosulphuret of soda.

Supertartrate of soda is readily obtained by adding tartaric acid to a solution of tartrate of soda. Thenard has treated upon this salt. See *Annales de Chimie*, tome xxviii. page 12.

Tartrate of soda. This salt may be formed by the direct union of tartaric acid and soda. It is composed of

1 proportional of tartaric acid	=	62.5
1 ditto of soda	=	29.5
		92.0

It crystallizes in needle-formed crystals, which are much more soluble in water than the tartrate of potash.

Tungstate of soda. This salt differs much from the tungstate of potash already described, as it crystallizes in solid elongated hexahedral tables; whereas the latter is incapable of crystallization, and, when concentrated as much as possible, deliquesces.

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[42] Dr. Thomson, vol. ii. page 449.

by exposure to a damp atmosphere. Tungstate of soda, which may be prepared by dissolving tungstic acid in a solution of soda, is soluble in four parts of cold, or two parts of boiling water. Vauquelin and Hecht have investigated the nature of the salts formed with tungstic acid [43].

Urate of soda. This salt is in the form of a white powder, having, according to Dr. Thomson, the same appearance as pure uric acid [44]. It is soluble in a lye of caustic soda.

It had for many years been usual to consider the fixed alkalies to be simple undecomposable bodies; but when the present modes of chemical analysis were adopted, it was soon suspected that soda and potash would ultimately be found to be compound substances. Morveau had long ago published an opinion that the fixed alkalies were not simple substances; and in the first edition of *The Chemical Catechism*, printed in the year 1806, I fully expressed my opinion of the compound nature of these bodies. In the year 1807 a very important paper was read by Sir Humphry Davy before the Royal Society, on the agencies of galvanism in the decomposition of a variety alkaline and earthy salts. The experiments which he detailed in that paper were sufficient to produce an alteration in all our former ideas of chemical affinity, as they proved decisively

[43] *Journal des Mines*, No. xix. page 80.
[44] *System of Chemistry*, vol. ii. page 454.

that the formation of all chemical compounds may depend on the electrical state of the materials of which they are composed. Soon afterwards, by means of the large galvanic apparatus at the Royal Institution, this philosopher was enabled to decompose the fixed alkalies, and to exhibit their metallic bases in an insulated and separate state.

It was on the 19th day of November, in the year 1809, that Sir Humphry Davy, in a paper read before the Royal Society, announced that he had succeeded in his attempts to decompose these bodies.—Of so much consequence are these discoveries, and so very interesting is the paper which details them, that I am sure I shall be expected in an Essay on the fixed alkalies not to withhold such an abridgement of it, as will give the reader a correct idea of the important matter which it contains, and also of the several circumstances which were connected with discoveries which are in themselves as truly valuable as they are brilliant and original.

In the first attempts which Sir Humphry Davy made for the decomposition of the fixed alkalies, he entirely failed, in consequence of his having acted upon their aqueous solutions. He afterwards used potash in the state of igneous fusion, and acted upon it by an electrical power, which was produced from a galvanic battery of 100 plates, of 6 inches square, highly charged.

Here some brilliant phenomena were produced. A most intense light and a column of flame were exhibited, which seemed to be owing to the deve-

lopment of combustible matter; and when the order was changed, so that the alkali was brought in contact with the negative side of the battery, aëriform globules, which inflamed in the atmosphere, rose through the potash. Being, however, unable to collect the products of decomposition by this means, he had then recourse to pure potash in its usual state, and depended on electricity alone for its fusion, as well as its decomposition.

A small piece of pure potash, moistened a little by the breath, was placed upon an insulated disc of platinum, connected with the negative side of a battery consisting of 100 plates of 6 inches and 150 of 4 inches square, in a state of intense activity, and a platinum wire, communicating with the positive side, was brought in contact with the upper surface of the alkali. Under these circumstances a vivid action soon commenced. The potash began to fuse at both its points of electrization, and small globules having a high metallic lustre, and precisely similar in visible characters to quicksilver, appeared, some of which burnt with explosion and bright flame. These globules, which appear to be metallic, are the basis of potash, that alkali being composed of this peculiar base and oxygen.

Soda, when acted upon in the same manner, exhibited an analogous result, and these effects equally took place in the atmosphere, and when the alkali was acted upon in the vacuum of an exhausted receiver: but these globules could not in either case be produced from *crystallized* alkalies.

When a globule of the base of potash was exposed to the atmosphere, it immediately attracted oxygen, and a white crust formed upon it, which proved to be pure potash. When the globules were strongly heated and then suspended in oxygen gas, a rapid combustion with a brilliant white flame was produced, and these metallic globules were converted to an alkali, whose weight greatly exceeded that of the combustible matter consumed.

When Sir Humphry Davy had thus detected the bases of the fixed alkalies, he had considerable difficulty to preserve and confine them, so as to examine their properties and submit them to experiments. He found, however, that in recently distilled naphtha they may be preserved many days, and that their physical properties may be easily examined in the atmosphere, when they are covered by a thin film of it.

The basis of potash, at 60° Fahrenheit, is only imperfectly fluid; at 70° it becomes more fluid; and at 150° its fluidity is perfect, so that different globules may be easily made to run into one. At 50° it becomes a soft and malleable solid, which has the lustre of polished silver; and at about the freezing point of water it becomes harder and brittle, and when broken in fragments exhibits a crystalline texture of perfect whiteness and high metallic splendour.

To be converted into vapour, it requires a temperature approaching that of a red-heat. It is an excellent conductor of heat, and a perfect conductor of electricity.

Resembling the metals in all these properties, it is, however, remarkably different from any of them in specific gravity; for it will not sink in double distilled naphtha, whose specific gravity is only .770, that of water being considered as 1.000. Sir Humphry Davy has determined by experiment that its specific gravity is to that of mercury as 10 to 223, which gives a proportion to that of water nearly as 6 to 10; so that it is the lightest metallic body known. When this substance is introduced into chlorine gas, it burns spontaneously with a bright red light, and chloride of potash is formed. When thrown upon water, it decomposes it with great violence, and instantaneous explosion is produced with brilliant flame, and a solution of pure potash is the result. When a globule is placed upon ice, not even the solid form of the two substances can prevent their union; for it instantly burns with a bright flame, and a deep hole is made in the ice, which is found to contain a solution of potash. When a globule is dropped upon moistened turmeric paper, it instantly burns, and moves rapidly upon the paper, as if in search of moisture, leaving behind it a deep reddish brown trace.

So strong is the attraction of the basis of potash for oxygen, that it discovers and decomposes the small quantities of water contained in alcohol and ether, even when they are carefully purified. When thrown into the mineral acids, it inflames and burns on the surface. In sulphuric acid, sulphate of potash is formed; in nitric acid, nitrous gas is disen-

gaged, and nitrate of potash formed. When brought in contact with a piece of phosphorus, and pressed upon, there is a considerable action; they become fluid together, burn, and produce phosphate of potash. When a globule is made to touch a globule of mercury about twice as large, they combine with considerable heat: the compound is fluid at the temperature of its formation; but when cool it appears as a solid metal, similar in colour to silver. If this compound be exposed to air, it rapidly absorbs oxygen; potash which deliquesces is formed; and in a few minutes the mercury is found pure and unaltered. When a globule of the amalgam is thrown into water, it rapidly decomposes it with a hissing noise, potash is formed, hydrogen disengaged, and the mercury remains free. The basis of potash readily reduces metallic oxides when heated in contact with them. It decomposes common glass by a gentle heat, and at a red heat effects a change even in the purest glass.

In his experiments on SODA, Sir Humphry Davy has discovered that its base, like that of potash, is white, opaque, and has the lustre of silver. The property of welding, which belongs to iron and platinum, at a white heat only, is possessed by this substance at common temperatures. It is very similar in its more obvious properties to the base of potash; but it has greater specific gravity, being that of water nearly as nine to ten, or as .9348 to to 10.000. In oxygen gas it produces a white flame, and sends forth bright sparks, occasioning a

very beautiful effect. In chlorine gas it burns vividly, with numerous scintillations of a bright red colour. In the quantity of one-fortieth, it renders mercury a fixed solid, of the colour of silver, and forms an alloy with tin. When amalgamated with mercury, the amalgam will combine with other metals. Sir Humphry Davy tried this with iron and platinum, and had reason to believe that these latter metals remain in combination with the mercury, even when deprived of the new substance by exposure to the air.

The whole of the sixth chapter of this very interesting paper is occupied with the detail of several curious and ingenious experiments to ascertain the proportions of the bases and oxygen in the two fixed alkalies; from whence he concludes that 100 parts of potash consist of about 84 basis, and 16 oxygen; and 100 parts of soda consist of about 76 or 77 basis, and 24 or 23 oxygen; or that potash may be considered as consisting of about 6 parts basis, and 1 of oxgen; and soda of 7 basis, and 2 oxygen.

In reply to the question, whether the bases of potash and soda should be called metals, it might be said that they agree with metals in opacity, lustre, malleability, conducting powers as to heat and electricity, and in their qualities of chemical combination. Even their low specific gravity does not appear a sufficient reason for making them a new class; for amongst the metals themselves there are remarkable differences in this respect, platinum being nearly four times as heavy as tellurium; and

tellurium is not much more than six times as heavy as the basis of soda. Conceiving the basis of the two fixed alkalies to be metals, Sir Humphry Davy has named one Potassium, and the other Sodium, adopting that termination which, by common consent, has been applied to other newly discovered metals.

In concluding this very important communication, Sir Humphry Davy remarks that an immense variety of objects of research is presented in the powers and affinities of the new metals produced from the alkalies. In themselves they will undoubtedly prove powerful agents for analysis; and, having an affinity for oxygen stronger than any other known substances, they may possibly supersede the application of electricity to some of the undecompounded bodies[45].

In sciences kindred to chemistry, the knowledge of the nature of the alkalies, and the analogies arising in consequence, will open many new views; they may lead to the solution of many problems in geology, and show that agents may have operated in the formation of rocks and earths, which have not hitherto been suspected to exist.

With respect to the properties of potassium, it may be said, in addition to those already detailed, that it is ductile, and of the consistence of soft wax; and though originally of great lustre, it immedi-

[45] A more extended view of the connexion between electrical and chemical attraction may be seen in Sir Humphry Davy's *Elements of Chemical Philosophy*, vol. i. page 158—173.

ately loses its brilliancy by exposure to the air. At a temperature higher than that at which water congeals, it is a hard and brittle substance; and at a red heat becomes dissipated in vapour. But it is, perhaps, one of the most curious properties of these metalloids, that if an alloy be formed, composed of one part of potassium and three of sodium, the compound will continue fluid at the low temperature of 32°.

Since the first edition of these Essays was published, a new fixed alkali called *lithia* has been discovered in the petalite, a mineral brought from the mine of Utoen in Sweden. This discovery was made by M. Arfvredson, a young Swedish chemist. The mineral called *spodumene* also affords the same substance, and it has likewise been found in crystallized *lepidolite*.

When *lithia* is submitted to the action of the voltaic pile, it becomes decomposed; and, similar to potash and soda, a metallic substance of great brilliancy and highly combustible is separated from it. Hence it appears that lithia, like the other fixed alkalies, is a metallic oxide, and from hence its metallic base is called *lithium*.

During the first analysis of the petalite, M. Arfvredson supposed its alkali to be soda; but he soon found that it differed from that alkali, and that it may be distinguished both from potash and soda by its power of neutralizing a much larger quantity of any acid.

Like the other alkalies, lithia is very soluble in water; and its solution, like theirs, possesses an acrid and nauseous taste. According to Vauquelin, lithia attracts carbonic acid from the atmosphere with great avidity, and in neutralizing the acids is more powerful even than magnesia. It consists of

Lithium	55.2
Oxygen	44.8
	100.0

Several salts have already been formed by the artificial combination of this new alkali with the acids, the chief of which are the chloride, the iodide, and the sulphuret of lithium; and the sulphate, the nitrate, the muriate, the phosphate, and the carbonate of lithia. Of these, the sulphate of lithia crystallizes in small prisms of a shining white colour. It is more fusible and soluble than sulphate of potash, and, unlike that salt, its taste is not bitter, but merely saline. The muriate and nitrate of lithia are both deliquescent salts; while the carbonate is efflorescent and sparingly soluble in water.

Lithia, like the other fixed alkalies, has the property of converting the vegetable blues to a green, and of turning the vegetable yellows brown. It is very sparingly soluble in alcohol.

In speaking of the fixed alkalies in connexion with the trade of the country, I might have observed that there are other sources from which the manufacturer may derive an abundant supply of the mineral alkali, besides those already mentioned. I refer

more particularly to the immense depositories of sea-salt which occur in various parts of the world, particularly in Hungary, Poland, Russia, Spain[46], and America, and to that inexhaustible source, the ocean itself, in which prodigious quantities of the same saline body are perpetually held in solution.

The rocks of salt in the British Islands are far from inconsiderable; but the many thousands of tons of it which are continually washing our shores, would furnish a most plentiful supply for every purpose whatever, whether for manufacture, agriculture[47], or any other branch of the arts. Its decomposition, so as to separate the soda, would not be difficult; and should this be effected, it would preclude the necessity of sending the wealth of the kingdom to foreign countries for the purchase of mineral alkali, would our Government allow us to take, without duty, that which Nature offers so profusely for our acceptance.

I am desirous, however, of inserting here a neces-

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[46] Near Cordova in Spain there is a mountain of rock salt 500 feet high, and three miles in circumference. But the largest mass of this salt hitherto discovered, is on the Missouri river in Louisiana, and this is 80 miles long, 45 miles in width, and of a prodigious height.

[47] Sea salt is perhaps of still more importance to the grazier than to the mere agriculturist, which is shown by the fattening quality of our salt marshes, and by the avidity with which all Neat Cattle devour their food when sprinkled with salt. See "*A Letter to the Farmers and Graziers of Great Britain, on the advantages of using Salt in the various branches of agriculture, and in feeding all kinds of farming stock; with a large Appendix of Proofs and Illustrations.*" By the author of these Essays. The fourth edition, price 2*s*.

sary caution.—The late Bishop Watson, in the first volume of his *Chemical Essays*, page 136, asks "Whether the alkaline part of rock salt may not be obtained by calcining it in conjunction with charcoal in open fires?" This passage, I suspect, has occasioned many persons to expend much money and time on a fruitless attempt; for I can assure the reader that I have submitted several hundred weights of this salt, mixed with a large portion of ground charcoal, to an intense heat in a reverberatory furnace*, where it was frequently stirred by a strong iron rake for thirty-six hours; and yet no decomposition whatever was effected.

If government would allow us either rock salt, or sea water, free of duty, various means entirely different from those suggested by Dr. Watson might be devised for producing an abundant supply of the alkali in question.

In the nineteenth volume of the *Annales de Chimie* there is a very valuable memoir by those eminent chemists, Le Blanc, Dezé, and Pelletier, and which was published by order of the Committee of Public Safety during the period of republicanism in France, that gives various methods by which muriate of soda (common salt) might be decomposed, and the alkali prepared for sale, so as to supersede the necessity of buying Spanish barilla.

This memoir, which is very long and circumstan-

* Drawings of the best kind of reverberatory furnaces for the decomposition of the alkaline sulphates are given in the plates, Nos. xvi. and xvii.

tial in its details, offers so many interesting considerations to the people of France, that an Englishman must be devoid of all patriotic feelings who could read it without wishing it were in his power to offer some other source of revenue to the consideration of his own Government, or some article equally efficient in its produce, to be accepted as a commutation for the present impolitic duties on salt [49].

This subject has often occupied the attention of Parliament, and the Reports of its Committees contain a variety of arguments and facts to show the existing necessity for the total repeal of the present laws relating to salt. The difficulties which have arisen whenever this business has been brought under consideration, have been many, and some of them so perplexing, as hitherto to have prevented the success of the several applications to the Legislature for the removal of the present impost. I do hope, however, that the time is not far distant when the matter will be again taken up by some competent individual, who will indefatigably pursue his object to its complete accomplishment, and who will no doubt be well supported in so patriotic a scheme for the benefit of the British nation.

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[49] For an account of the progress which has been made in repealing the duty on salt, see the Appendix. Also a book entitled "*Thoughts on the Laws relating to Salt.*" By the Author of these Essays. Sold by Baldwin, Cradock, and Joy, Paternoster Row, London.

stage of society. This application of it is indeed known to have been very ancient. The celebrated Tower of Babel, 2,200 years before Christ, was built with bricks [1]; and when the Israelites sojourned in Egypt 600 years afterwards, their taskmasters employed them chiefly in this kind of manufactory [2]. Bricks of clay were used also by other nations of antiquity. The Romans in particular had acquired great skill in the method of making, and also in the manner of burning, their bricks. This will appear by a comparison of the bricks that compose any of their edifices, with those of the present day. The Roman wall at St. Alban's (the ancient city of Verulam) is a direct proof of this assertion [3].

It was probably not long after the employment of clay in making bricks, that mankind learnt the art of using it in various other ways [4], and acquired methods of moulding it into vessels of capacity, and utensils for culinary purposes. Accordingly the

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[1] "And they said one to another, Let us make bricks, and burn them thoroughly." *Genesis* xi. 3, 4.

[2] "And the Egyptians made the children of Israel to serve with rigour. And they made their lives bitter with hard bondage, in mortar and in bricks." *Exodus* i. 13, 14. See also chap. v. verses 6—19.

[3] See Mr. J. Webster's Letter to Bishop Littleton, on this subject, in the 2d vol. of the *Archæologia*, page 184. See also some observations on the Ruins of a Roman wall at York, by Martin Lister, Esq., in the *Phil. Transactions*, vol. xiii. p. 238. The bricks in this wall were 17 inches long, 11 inches broad, and 2½ inches thick, and they were all extremely hard.

[4] From the accounts of many respectable travellers into Egypt, we learn that the inhabitants of that country, when they

most ancient writers we have, mention earthen vessels [5], and they speak of them as if they had been in use from time immemorial. It appears also that considerable pains were taken in tempering the clay for these purposes, for we read that this process was performed by treading it with the naked feet [6].

In the fifth volume of the *Archæologia* is an account of two vases, of great antiquity, which were found on the Mosquito shore in South America, and which are now in the possession of Lord Hillsborough. The account of them is transmitted by Governor Pownal, who says, "It is a decided fact that they were made in South America, and that they are curious exemplars of some of the first efforts of human ingenuity, and remains of what are become antiquities even among the Indians." He also says that remains of ancient potteries have been discovered high up the Black River, on the Mosquito coast, and that Father D.

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wished to make their granaries secure, put their seal on a handful of clay spread over the lock of the door; and as it appears from the testimony of the most ancient book now extant (the book of Job) that this was practised in the earliest times, it is more than probable that clay was then used for several *other* important purposes. Norden, part i. page 72. Dr. Pocock, vol. i. page 26. Job xxxviii. 14.

[5] "But the earthen vessel wherein it is sodden shall be broken." *Levit.* vi. 28. "And the Priest shall take water in an earthen vessel." *Numb.* v. 17. "Thou shalt break them with a rod of iron, thou shalt dash them in pieces like a potter's vessel." *Psalm* ii. 9.

[6] "And he shall come upon princes as upon mortar, and as the potter treadeth clay." Isaiah xli. 25.

Acuina mentions, that some of the Indians on the river of the Amazons had carried this ancient manufactory to a great extent, so as even to establish a traffic for it with the neighbouring nations [7].

From a variety of testimonies we learn that the Greeks very early acquired proficiency in the arts of pottery. Mr. Fordyce, in describing the theatre of Herculaneum, has told us, that they had contrived how to form earthen vessels which had the property of increasing the voices of their actors [8].

According to Herodotus, however, vessels of earthenware were in his time extremely scarce, and highly esteemed by the nations around them. "Twice in every year," says he, "there are exported from different parts of Greece to Egypt, and from Phœnicia in particular, wine secured in earthen jars, not one of which jars is afterwards to be seen; for the principal magistrate of every town is obliged to collect all that are imported to the place where he resides, and send them to Memphis. The Memphians fill them with water, and afterwards transport them to the Syrian deserts. Thus all the earthen vessels carried into Egypt, and there carefully collected, are continually added to those already in Syria [9]."

And yet, from a passage in Juvenal, who wrote in the first century of the Christian æra, and five

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[7] *Archæologia*, vol. v. p. 318.

[8] *Memoirs concerning Herculaneum*, by W. Fordyce, M.A. London, 8vo, 1750, p. 16.

[9] Beloe's *Herodotus*, book iii. s. 6.

hundred years previous to Elizabeth, it seems that, notwithstanding the former opinion, earthenware was then made in great plenty in Egypt.

Hæc inter rubræ subeliæ et inutile vulgus,
Parvula fictilibus solitum dare vela phaselis,

On these lines it may not be amiss to transcribe the commentary of Mr. Harmer. "Juvenal," says he, "describes the boats of the Egyptians as if they were of earthenware, and not one of the variorum notes explains this, though it may be easily done from modern travellers. All that is meant is, that sometimes the Egyptians make use of rafts, which were made to float, by means of empty vessels of earthenware fastened underneath them."

"In order to cross the Nile," Norden tells us, "the inhabitants have recourse to the contrivance of a float made of large earthen pitchers, tied close together, and covered with leaves of palm trees. The man that conducts it has commonly in his mouth a cord, with which he fishes as he passes on. These are undoubtedly the earthenware boats of Juvenal."

"The word *pictæ* is not to be understood as signifying their being beautified with a variety of

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[20] *Juven.* Sat. xv. ver. 126—128.

——————"who drive with little sail
Their earthen boat before the summer gale,
Or through the tranquil water's easy swell
Work the short paddles of their painted shell."

Hodson's *Juv.* 4to, London 1807, p. 288.

colours; but means their being rubbed with some substance that might fill up the pores so as to prevent the water penetrating into the cavity of the pitchers, which if it did in a considerable degree, might occasion the sinking of this kind of vessel; for the Egyptian earthenware is said to be very porous."

"It may be proper to observe that these floats are not constructed to pass up and down the Nile like boats, or designed to carry goods upon them, though they may occasionally be put to that use; it is only an easy way which they have discovered of conveying their earthenware from Upper Egypt, where it is made, to the lower parts of that country; where on their arrival the float is taken to pieces, and the pitchers sold to the inhabitants [11]."

According to Vitruvius, who wrote in the time of Augustus Cæsar, the ancient Romans made their water-pipes of potter's clay. These were generally two inches thick, and joined together with common mortar mixed up with oil. When they had a joint to make, they employed also a piece of free-stone, which they pierced through to receive the two ends of the pipes to strengthen and secure them in the manner of a bandage. Some of these

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[11] Harmer's *Observations on diverse Passages of Scripture*, Dr. Clarke's edition, vol. i. page 90—94.

[12] Switzer's *Hydrostatics*, 4to, 1729, p. 116.

[13] In the *Philosophical Transactions*, vol. xv. page 1017, is an account of a fine Roman earthen vessel found near York, with the figure of a female face upon it, of the natural size. It was sent to the Ashmolean Museum in Oxford.

pipes were taken up a few years ago in Hyde Park [12].

The people of Britain in ancient times were furnished with earthen vessels by the Phœnicians; and they no doubt soon learnt to make others in imitation of them. Many urns of earthenware, supposed to have been the workmanship of the ancient Britons, have been found in barrows in different parts of this kingdom. It is also well known that the Romans made use of earthenware, and that they greatly excelled in the art of making it [13], as well as in the manufacture of bricks and tiles [14]. Vestiges of several of their great potteries [15] are still discernible in many parts of this island [16].

There is reason to believe that there was once a considerable manufactory of Roman earthenware, on a small island which 2000 years ago stood in the mouth of the Thames, at the back of Margate Sand, now known by the name of the Queen's Channel, at about two leagues from the coast. Governor Pownal, who has written a memoir on

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[12] Giraldus Cambrensis, in his Topography of Wales, written in the 12th century, describes Caerleon in Monmouthshire, the ancient *Isca Silurum* of the Romans, as containing stately palaces covered with *gilt* tiles. *Itinerary* of Archbishop Baldwin, page 836.

[15] In the *Philosophical Transactions*, 1695, vol. xix. p. 319, is an account of a Roman Pottery discovered about two miles from Leeds, the old *Leogeolium*. The village that succeeded the old pottery is now called *Potter Newton*. *Philosophical Transactions*, 1700, vol. xxii. page 564.

[16] Henry's *History of Great Britain*, 2d edit. 8vo, vol. ii. page 140. Borlase's *Antiq. of Cornwall*, page 236.

this subject, says that fishermen have occasionally, for many years, taken up with their nets complete pieces of earthenware from this particular spot. They are all of coarse workmanship; but he supposes that this was a manufactory specially employed in making earthen vessels to be used according to the Roman ritual in their religious ceremonies. Each vessel has Atillianus, the name of the maker, neatly impressed upon it [17].

It is probable that the early inhabitants of the world arrived nearer to perfection in the modelling of clay, and in the making of earthen wares, than in the management of any other manufactures; for in the kingdoms of China and Japan [18], not only common earthenware, but even porcelain [18] of very excellent quality, was made long before the commencement of the Christian æra.

"First China's sons, with early art elate,
Form'd the gay tea-pot and the pictured plate;
Saw with illumined brow and dazzled eyes
In the red stove vitrescent colours rise [20];

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[17] *Archæologia*, vol. v. page 282, &c.

[18] This manufacture is still of great importance in China. At present "there are five hundred furnaces at work, and nearly a million of men employed, at King-to-Ching, a province of Kian-si." Chaptal's *Elements of Chemistry*, 8vo, 1791, vol. ii. page 94.

[19] Whitaker, in his Account of the Course of Hannibal over the Alps, says, that the name Porcelain comes from the herb *Purslain*, which has a purple-coloured flower, like to the ancient china, which was always of that colour. Vol. i. 8vo, 1794, page 55.

[20] "No colour is distinguishable in the red-hot kiln of the potter, but the red itself, till the workman introduces a small

Speck'd her tall beakers with enamell'd stars,
Her monster-josses and gigantic jars;
Smear'd her huge dragons with metallic hues,
With golden purples, and cobaltic blues;
Bade on wide hills her porcelain castles glare[21],
And glazed pagodas tremble in the air."

It appears also that porcelain, as well as earthenware, was made in ancient Egypt; for several small earthen figures are frequently found deposited with the Egyptian mummies, resembling them in shape, and covered with a blue glazing similar to that of the Chinese porcelain. Du Halde has said that lapis lazuli abounds in Egypt, and hence some have supposed that this blue has been produced by ultramarine[22]. This, however, could not have been the case, as it is now well known that any colour made from lapis lazuli would instantly be destroyed by the intense heat of a potter's oven[23].

Anxious to ascertain what article could have been employed to produce so beautiful a colour in such early times, Mr. Delaval broke off a piece of the blue enamel from one of these small images, and submitted it to a variety of experiments and to the

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piece of dry wood; which by producing a white flame renders all the other colours visible in a moment." DARWIN.

[21] This refers to the porcelain buildings of the Chinese. An account of a very singular one will be found in the *Chemical Catechism*, tenth edition, page 103.

[22] Norden has, however, fallen into this error. See his *Travels*, part ii. p. 75, 76.

[23] See Klaproth, *Annales de Chimie*, xxi. p. 150, and Guyton on the colouring Principle of the Lapis Lazuli, in the xxxivth vol. of the *Annales de Chimie*, p. 58; also, in Nicholson's *Journal*, 4to, vol. i. p. 77, and vol. iv. p. 311.

action of several chemical tests. In all these cases, the results were exactly what he would have expected had he operated on a piece of modern enamel which had been coloured with the blue oxide of cobalt[24]; the very article which the potters of the present day employ. What an idea does this give of the attainments of the Egyptians, more than two thousand years before the science of chemistry had made any progress in Europe!

That porcelain was not uncommon in Europe during the first century of the Christian æra, is evident from the discoveries that were made in the excavations of those cities which were destroyed by the eruption of Vesuvius in the first year of the reign of the emperor Titus. For, according to the catalogue made by Bayardi, there were no less than 193 vases and other utensils of earthenware and porcelain taken out of the ruins of Herculaneum[25].

We are not however to suppose that these porcelain vessels were of European manufacture; for we are expressly informed that the first porcelain which was seen at Rome was brought thither from Pontus in Asia, by the victorious army of Pompey, and that this was only sixty-four years before Christ[26].

This in some measure accounts for the great excellence which the Persians have arrived at in this elegant art. Sir John Chardin, who travelled through Persia about the middle of the 17th cen-

[24] See "*An Experimental Inquiry into the Cause of the Changes of Colours in Opake and Coloured Bodies.*" By Edward Hussey Delaval, 4to, London, 1777.

tury, has taken notice of their beautiful porcelain, and quotes a passage from Propertius, one of the writers of the Augustan age, to show the antiquity of the art among that people[27].

The Etruscans, who were probably a colony from Phœnicia, are noted by the early writers for their excellence in the manufacture of porcelain. Dr. Darwin, who was intimately acquainted with the great Mr. Wedgwood, and knew all his sources of information, supposes that their principal manufactories were about Nola, at the foot of Vesuvius, and that they learnt the art from the Chinese. This elegant writer has thus given his testimony to the superiority of their productions:

"Etruria! next beneath thy magic hands
Glides the quick wheel, the plastic clay expands:
Nerved with fine touch, thy fingers (as it turns)
Mark the nice bounds of vases, ewers, and urns;
Round each fair form in lines immortal trace
Uncopied Beauty, and ideal Grace."

The art of painting vases in the manner of the Etruscans has been lost for ages, and this is supposed, by the author of the Dissertations on Sir William Hamilton's Museum, to have happened in the time of Pliny. The honour of the recovery of this long-lost art does not however belong to the late Mr. Wedgwood, as has been asserted; for

[25] See the 1st vol. of Martyn and Lettice's *History of the Antiquities of Herculaneum.*
[26] Pliny, l. xxxvii. § 2.
[27] Sir John Chardin's *Travels in Persia*, folio, London, 1686.

though he was the first to imitate the correct and beautiful forms of the Etruscan vases and the paintings upon them, his vases were painted by a different process from that which was employed on the urns, &c. of the ancients[28].

Mr. Harmer informs us that the best Asiatic porcelain is manufactured at Skiraz, the capital of that province, which is distinguished from the other provinces of that country by the name of Persia properly so called; also at Metched, the capital of Bactriana; at Yesd, and at Kirman, in Caramania; and in particular in a town of Caramania called Zorendi. The earth of which these vessels are made, is a pure enamel within, as well as without, like that of the Chinese porcelain; its grain is as fine, and it is as transparent; so that it frequently equals and sometimes even excells that of the Chinese, its varnish is so exquisite.

The Persian porcelain has another excellence, that it resists fire, so as not only to allow of water being boiled in it, but the vessels for the express purpose of boiling are made of it. It is so hard, that it is employed in making mortars for grinding colours, and for pounding other things; and also for the moulds for making bullets. The materials of which this beautiful porcelain is made are glass and the small pebbles found in rivers, ground very fine; with a slight mixture of argillaceous earth.

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[28] See the Catalogue of Cameos, Intaglios, &c. 8vo, printed for Cadell, 1773.

It is said that the potters of the city of Yesd, in Caramania, already mentioned, sent one day to the potters of Ispahan, as it were in defiance, a porcelain vessel, which would hold six English quarts of water, and yet weighed only the eighth part of an ounce[29]. I mention this anecdote, to show what perfection the inhabitants of Persia have attained in this manufacture.

In connexion with this account of the excellence of the Persian porcelain, it is related that in the year 1666, an ambassador of the Dutch East India Company having brought many rich presents for the Persian court, and ignorant of the value which this people set upon their own manufacture, brought, among other articles, fifty-six pieces of old China porcelain; and that the king when he saw them laughed heartily in derision, asking with an air of contempt what they were. The Dutch merchants frequently mix this Persian porcelain with that of China in what they send to Holland[30], for the supply of that market.

The Barbarini or Portland vase, has sometimes been adduced as a proof that the ancients had arrived at great excellence in the manufacture of porcelain. This beautiful piece of antiquity was discovered in the tomb of Alexander Severus, who died so early as the year 235, and the late Duchess of Portland actually paid a thousand guineas for it.

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[29] Harmer's *Observations*, vol. i. p. 75.
[30] *Ibid.* vol. i. p. 74, 75.

But unfortunately for such a speculation, this exquisite piece of workmanship is not made of porcelain, but of glass.

A thick coat of white semi-transparent glass covers the whole of this urn, which is itself made of a deep blue glass, and the white covering appears to have been cut by the lapidary in the same way as the subjects of antique cameos on coloured grounds. Siracides relates that the ancients had also the art of covering *earthen* vessels with a crust of glass. Mr. Wedgwood's imitation of this elegant piece of antiquity is however of *porcelain*, and deserves every commendation that can be bestowed upon it. The history of this production may be given in a few words.

Several of the nobility and gentry being desirous of having a copy of this beautiful piece of antiquity, they engaged Mr. Wedgwood to endeavour to imitate it; and he actually produced a vase which for elegance and beauty was considered to be fully equal to the original. The subscription was for fifty vases at 50*l.* each; and notwithstanding the large sum to which this subscription amounted, such heavy expenses were incurred in their fabrication that Mr. Byerley, the partner of Mr. Wedgwood, has assured me that they lost money by the undertaking. Mr. Webber the artist received five hundred guineas for modelling it.

In attempting the history of the manufacture of European porcelain, it may be remarked, that al-

though porcelain had been brought into this quarter of the world before Christ, as has been mentioned above, there is reason to believe that the introduction of the knowledge of making porcelain in Europe was but of late years, as will be seen in the sequel[31]. Porcelain is not made even now in the Indies; what is consumed there is all imported either from Persia, Japan, or China, and the other kingdoms between China and Pegu.

The English cannot, I presume, lay claim to much excellence in their manufacture of earthenware before the time of the late Mr. Wedgwood, who began his indefatigable researches about the year 1750: for, in the beginning of the last century, all the best tiles and even the finer sort of bricks were imported from Denmark, Germany, and Holland[32]. Not but that bricks and tiles of clay had long been made amongst us; for there is an act of parliament now on the statute books, that was passed in the reign of Edward IV[33], which directs the time for digging the earth, the manner of making the bricks, &c.; and it is so expressed, that we have reason to conclude that bricks had been made in England from time immemorial. While on this article, I am desirous of mentioning that there is a paper on the process of burning bricks, in the third volume of Bergman's Chemical Essays, and that it

[31] Harmer's *Observations*, vol. i. p. 75.

[32] Houghton's *Collections for the Improvement of Husbandry and Trade*, vol. ii. p. 26.

[33] See 17th Edward IV, cap. 4.

contains many hints which may be useful to those who are engaged in that occupation.

It seems strange that our remote ancestors did not arrive at greater perfection in the manufacture of all these articles, when it is considered that the island produces not only a great variety of clays, but also all the other materials necessary for the production of the best earthenware and porcelain: Dr. Martin Lister, who wrote in the latter part of the seventeenth century, distinguishes no less than two-and-twenty different sorts of clay in Britain which fell under his own observation[34]. Moreover, the exquisite pieces of workmanship which were produced at different periods by the English sculptors, show that there was no deficiency of genius and skill among our artists, who probably conceived that the working in clay was beneath their attention.

Walter de Colecester, sacrist of the abbey of St. Alban's, is mentioned by Matthew Paris, his contemporary, as an admirable statuary; and several of his works are described as exquisitely beautiful[35].

Three English artists of London, whose names are recorded, made the celebrated alabaster tomb of John IV, duke of Brittany, carried it over to Nantz in a finished state, and erected it in the cathedral there, A.D. 1408[36].

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[34] *Phil. Trans.* No. 164, page 255. Campbell's *Political Survey of Great Britain*, 4to, 1774, vol. ii. page 16.

[35] M. Paris. *Vitæ Abbatum*, p. 80, &c.

[36] Rymer's *Fœdera*, tom. viii. page 510.

Pliny informs us, that Praxiteles, the famous statuary of antiquity, used to say that "the invention of modelling clay into figures had given birth to the art of making statues of marble and of bronze[37]." But Dr. Shaw tells us, the Grecian artists did not begin to use marble either in sculpture or building till the year 720 before Christ. The Jewish people might probably employ it two or three hundred years sooner, which is about the time that ivory houses and ivory palaces are mentioned in the Scriptures[38].

In returning from this digression, I have to observe, that the common stoneware, and that called white enamel, have been made in various countries of Europe ever since the fifteenth century. The former of these is distinguished by a glaze made by means of muriate of soda; the latter is covered with a real glass, rendered opaque by the white oxide of tin[39]. Stoneware is the only article of pottery that can be employed for chemical purposes, where a great heat is required. Macquer says that our best common stoneware is the most perfect pottery that can be, and that it has all the essential qualities of the finest old Japanese porcelain. Mr. Pott, the author of *Lithogeognosia*, has written a treatise expressly to explain the requisite perfections of

[37] Plin. lib. xxxv. § 45.

[38] Shaw's *Travels in Barbary and the Levant*, page 172. I Kings, chap. xxii. verse 39. Amos iii. 15.

[39] The oxides of many other metals are used in different branches of pottery, as will be shown in connexion with the latter part of this subject.

stoneware for the purpose of chemical vessels; but I conceive that what is made at Lambeth near London by the best of those manufacturers, is susceptible of but little improvement. For boiling syrups, and for many other culinary purposes, the Lambeth stoneware is the best article that can possibly be employed; as it is cheap, will stand a great heat, and is perfectly wholesome; whereas many of the earthen utensils used in our kitchens are glazed with lead, and consequently are extremely dangerous. Several years ago, I adverted to this subject in another work; but I was desirous of repeating the admonition now, because I consider the health of the community must be impaired by the frequent use of earthen vessels which are covered with the common Staffordshire glaze. The acetic acid will readily dissolve the oxide of lead; hence the boiling of pickles, and the making of other culinary preparations in such vessels, must be highly improper.

The white enamel ware was brought to its present state of perfection by Bernard de Palissy, a native of the diocese of Agen, in the province of Guienne in France; a spot celebrated for being the birthplace of the memorable Joseph Scaliger[40].

Palissy was in a low station of life; but he was

[40] Scaliger is called *memorable*, because he was not only well versed in all the sciences, but understood thirteen different languages: It has been said that he was the most learned man that any age ever produced. The variety of subjects on which he wrote with applause is truly astonishing.

eminent for his knowledge, industry, and talents. There were indeed so many interesting traits in his character, that I trust I shall be excused if I recite a few of the chief circumstances of his history.

He is said to have been a skilful painter upon glass [41], but he was more generally known as a chemist. Originally he was a land surveyor and draughtsman; but his taste for natural history led him to abandon this employment, and induced him to travel for instruction over the whole of France and Lower Germany. An accidental circumstance threw into his hands a cup of enamelled pottery; and, from that time, his whole attention and fortune were taken up in experiments on enamels [42]. Nothing can be more interesting than the narrative which he himself has given of his labours.

He exhibits himself as building and rebuilding his furnaces, always on the eve of success; worn out by labour and misfortune; the derision of the public; the object of the angry remonstrances of his wife; and then as being reduced to such an extremity as to burn his furniture, and even some of the wood-work of his house, to keep his furnaces going.

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[41] In the time of Palissy the art of painting upon glass was nearly lost. In this country it was classed with the ARTES PERDITÆ; but Mr. Walpole has shown, by a regular series of artists and their performances, that this secret was never entirely lost. Walpole's *Anecdotes of Painting*.

[42] The modern enamel painting is quite a different art. This was invented by John Petitot of Geneva. An account of his experiments and discoveries may be seen in the Biographical Dictionary, article Petitot, and also in Grainger's Biographical History, vol. ii. p. 288.

His workman presses him for money, he strips himself, and gives him part of his clothes. But at length, by dint of indefatigable labour, constancy, and genius, he arrived at the desired degree of perfection, which gained him the esteem and consideration of the greatest men of his age.

He was the first who formed a collection of natural history at Paris. He even gave lectures on that science, and received a moderate subscription from each of his auditors, under the obligation of returning it four-fold if any thing he taught should prove false. He was the author of many singular books on subjects of agriculture, fire, earth, salts, &c. that are now very difficult to be found, and it is to him especially that Buffon is indebted for many useful hints.

Palissy was the first who ventured, in the face of the priests, to affirm that fossil shells and calcareous mountains are the remains of real shells; he was also the first who taught the true theory of springs, and was in all respects an eminent and accomplished man.—The very form of his works exhibits a proof of original genius; they consist of dialogues between Theory and Practice, in which Practice is always the instructor, while Theory is represented as a scholar proud of his own understanding, but indocile and ignorant.

The high reputation he acquired, and the obligations under which his countrymen stood indebted to him, were however not sufficient to defend him from the persecution of the League; for, being a

protestant, Matthew de Lawnay[43], one of the greatest fanatics of his day, caused him to be dragged to the Bastile at the age of ninety years, where he signalized himself by acts of firmness and heroism.

His reply to Henry III. deserves to be commemorated. "My good man," says the King, "if you cannot reconcile yourself to the matter of religion, I shall be compelled to leave you in the hands of my enemies." "Sire," said Palissy, "I was perfectly ready to surrender my life; and if the action could have been accompanied with any regret, certainly it must have vanished, after hearing the great King of France say, 'I am compelled.' This, Sire, is a situation to which neither yourself, nor those who force you to act contrary to your own disposition, can ever reduce me, because I am prepared for death; and because neither Your Majesty nor your whole people have the power to compel a simple potter to bend his knee before the images which he fabricates[44]." This venerable man died about the year 1590.

Several of the nations of Europe at the dawn of the eighteenth century, could not but regret that the knowledge of the manufacture of porcelain had not been introduced among them. At this time, how-

[43] This man must not be confounded with the celebrated De Launay who wrote "Remarks on the Roman Jurisprudence," and died in 1693.

[44] Chaptal's *Elements of Chemistry*, vol. ii. p. 90; and the *Biographical Dictionary*, article Palissy.

ever, a fortunate circumstance aroused the attention of the French people, and directed it to this important subject.

Francis D'Entrecolles, who had resided many years in China as a Christian missionary, a man of insinuating manners, and of a mild and affable deportment, had the address to procure specimens of the materials used by the natives in their porcelain, and these he sent to France with a summary description of the Chinese processes.

It may appear strange that so jealous a people as the Chinese are known to be, should have allowed of European missionaries being settled among them. The ecclesiastical historian Mosheim has, however, investigated this subject, and it is highly amusing to read his account of the arts which the Jesuits practised to interweave the doctrines of Jesus with those of Confucius, and to learn how they ingratiated themselves with the inhabitants of that country[45].

When the specimens arrived in France, the celebrated Reaumur undertook a series of experiments to discover the method of imitating the Chinese productions; and he persevered with amazing industry until he had obtained the main object he had in view.

The difficulties which he had to encounter; the mistakes he made during the investigation; the cause of those mistakes, and the extent of his suc-

[45] See an octavo pamphlet printed by Tonson in 1750, entitled "Authentic Memoirs of the Christian Church in China."

cess, are all well detailed in the French Dictionary of Chemistry, translated by Mr. Keir, and will be found under the article Porcelain. Mr. Reaumur himself in the years 1727 and 1729 also published a full account of his progress in this inquiry, in two memoirs addressed to the Academy of Sciences, and which were printed in their Transactions.

While Reaumur was engaged in these experiments, porcelain was begun to be manufactured in Saxony, and soon afterwards other manufactories of it started up in different parts of Germany. We had also an establishment for making it at Chelsea; and since that period various companies in different parts of England, France, and Italy, have been founded for the same purpose.

The first person who made porcelain for sale in Saxony was the Baron Botgar, and it is probable that his was the first manufactory of real porcelain in Europe. In order as much as possible to preserve this art as a secret, the works were rendered impenetrable to any but those who were immediately employed in them[46].

M. De la Condamine, in his journey into Italy, visited a manufactory of porcelain established at Florence by the Marquis de Ginori, governor of Leghorn, where he saw statues and groups half as large as nature, and modelled from some of the finest antiques. He describes the body of the ware

[46] See the *Travels of Jonas Hanway*, in 4 volumes, 4to, London, 1753.

as being equal to the best Chinese manufacture, and that it would be extremely beautiful if it had a whiter glazing; but that the Marquis was determined to use only such materials as were found in his own country. How superior are the advantages which the English nobility possess for improving the manufactures of these kingdoms, if it were thought becoming in them to attend to such objects! In France, the Count de Lauraguais engaged in the pursuit of improvements in porcelain for several years with uncommon ardour and success. *French Chemical Dictionary.*

The establishments of the most consequence among the moderns are, one at Dresden; the King of Prussia's own manufactory at Berlin; and the extensive works which belonged to the late King of France at Sevres[47], near Paris. There is also a considerable establishment for the manufacture of porcelain at Montpellier; a descriptive account of which, together with the process for making the peculiar glaze which is employed there, was published some years ago in the *Annales de Chimie*[48].

Frederick the Second, King of Prussia, had conceived so high an opinion of the importance of the manufactory at Dresden, that when he conquered Saxony he took many of the best workmen away by force, and transported them to his own pottery at

[47] For an interesting account of the establishment and management of the manufactory at Sevres, see the Memoir of Brongniart, the superintendant of the works. *Phil. Mag.* vol. xiii. p. 342; and vol. xiv. p. 17, &c.

[48] *Annales de Chimie*, tome ii. p. 73—85.

Berlin[49]. This manufactory at Berlin since the year 1763 has been carried on for His Majesty's own private account, with success and with good taste. Five hundred men have constant employment in it, and large quantities of the porcelain are annually exported[50].

Mr. Jonas Hanway, in the account of his travels, has published a particular detail of an immense collection of porcelain which is laid up in the Chinese palace at Dresden. The whole recital would be unsuitable to these Essays; but the following particulars will show how the Elector of Saxony valued himself on account of the perfection to which the manufacture of porcelain had arrived in his dominions[51].

"The vaults of this palace," says he, "consist of fourteen apartments filled with Chinese and Dresden porcelain. One would imagine there was sufficient to stock a whole country; and yet they say, with an air of importance, that a hundred thousand pieces more are wanted to complete the intention of furnishing this single palace."

Here are a great number of porcelain figures of wolves, bears, leopards, &c., some of them as big as

[49] Wraxall's *Memoirs of the Courts of Berlin, Dresden, &c* 2 vols. 8vo, London, 1806.

[50] Busching's *Tour;* and the Appendix to the *Monthly Review*, vol. lv. p. 554.

[51] The potters of Dresden were always as curious in the management of their ovens as they are in the manufacture of their porcelain. Nothing but white wood is employed for heating the kilns, and this is never used till it is become thoroughly dry.

the life; a prodigious variety of birds, and a curious collection of different flowers. A clock is preparing for the gallery, whose bells are to be also of porcelain: I heard one of them proved, and think they are sufficient to form any music; but the hammers must be of wood."

Here are forty-eight large China vases, which appear to be of no use, nor any way extraordinary, except for their great size; and yet His Polish Majesty purchased them of the late King of Prussia at the price of a whole regiment of dragoons[52]."

In the course of the narrative, Mr. Hanway mentions one very interesting circumstance, viz. that samples of the *first efforts* to make china in Saxony were laid up by the King of Poland in this palace, together with specimens of all the improvements, in their several gradations, from the first, till the time when the manufactory arrived at its utmost state of perfection[53]; an idea truly philosophical, and which reflects more honour on his memory than the bartering away the liberties of his subjects for pieces of foreign porcelain.

The passion for collecting porcelain has been common in most countries. Dr. Campbell remarks

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[52] *An Historical Account of the British Trade over the Caspian Sea, with a Journal of Travels,* by Jonas Hanway, 4 vols. 4to, London, 1753.

[53] The potters in Saxony are so exact in the management of their manufactories, that they employ none but the purest rain-water for soaking the clay; and they prepare the clay only twice a year, at the equinoxes; conceiving that at those seasons the water is less contaminated with foreign ingredients.

that "to Ormus, at the proper season of the year, resorted the merchants from Persia, Arabia, and Turkey. At these seasons," he says, "the city wore a new face, the outsides of the houses were adorned with cabinets of porcelain, and with beautiful paintings; and all the riches of the East blazed in the eyes of the captivated spectator[54]."

The greatest part of the earthenware that is now made in England is manufactured in a particular district of about ten miles extent, well known by the name of the Staffordshire Potteries[55]. Here earthenware has probably been made ever since the time of the Romans[56]; but there did not appear to have been any ambition among the manufacturers to improve the art, or to produce any works of taste, till the late Mr. Wedgwood engaged in the business. This most excellent man brought modellers from Italy and from other parts of the continent, whom he engaged at high wages; and he also constantly employed a competent chemist in experiments[57], that nothing might be wanting which could conduce to extend the employment of earthenware throughout Europe, or that could in any way tend

[54] *Political Survey*, vol. i. p. 37.

[55] Some account of this manufactory may be seen in Plot's *History of Staffordshire*; in Arthur Young's *Six Months Tour through the North of England*, in 4 vols. 8vo, London, 1770; in Aikin's *Account of the Country round Manchester*; and in *the Chemical Catechism*, chap. v. page 110.

[56] In sinking pits very evident remains of Roman potteries have been discovered, and at a considerable depth below the present surface of the land.

[57] See the first vol. of these Essays, page 22.

to give a permanency to the staple manufactory of the county which had given him birth.

The tribute which an elegant modern poet has paid to the peculiar industry and genius of this very eminent man, is so just, and at the same time so beautiful, that, I do hope, no reader of taste will blame me for its insertion.

"Gnomes! as you now dissect with hammers fine
The granite rock, the noduled flint calcine;
Grind with strong arm, the circling chertz betwixt,
Your pure kaolins and petuntses mixt[58];
O'er each red saggar's[59] burning cave preside,
The keen-eyed Fire-Nymphs blazing by your side;
And pleased on WEDGWOOD ray your partial smile,
A new Etruria decks Britannia's isle.—

"To call the pearly drops from Pity's eye;
Or stay Despair's disanimating sigh,
Whether, O Friend of Art! the gem you mould
Rich with new taste, with ancient virtue bold;
Form the poor fetter'd SLAVE on bended knee[60]
From Britain's sons imploring to be free;
Or with fair HOPE the brightening scenes improve,
And cheer the dreary wastes of Sydney-cove;

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[58] Kaolin is the name of a native earth found in China, and employed by the potters of that country as one of the principal ingredients in their porcelain. Petuntse is a siliceous stone found also in China, and is the other ingredient with which they form the body of their porcelain. The former answers to our china clay, the latter to our Cornish granite. A more detailed account of the nature of petuntse may be collected from the article "Porcelain" in Macquer's *Chemical Dictionary*; from Watson's *Chemical Essays*, vol. ii. page 274, and Murray's *System of Chemistry* vol. ii. page 253.

[59] Saggar is the technical name of those coarse earthen vessels in which plates and all the smaller articles of pottery are placed before they are submitted to the heat of the potter's oven.

[60] Alluding to two cameos of Mr. Wedgwood's manufacture; one of a Slave in chains, of which he gratuitously distribu-

Or bid Mortality rejoice and mourn
O'er the fine forms on Portland's mystic urn [61]."

"Whether, O Friend of Art! your gems derive
Fine forms from Greece, and fabled gods revive;
Or bid from modern life the portrait breathe,
And bind round Honour's brow the laurel wreath;
Buoyant shall sail, with Fame's historic page,
Each fair medallion o'er the wrecks of age;
Nor Time shall mar, nor Steel, nor Fire, nor Rust,
Touch the hard polish of the immortal bust."

In justification of the very handsome tribute which the poet has thus paid to the immortal Wedgwood, it is proper to observe, that amidst a collection of the most beautiful medallions of British and Foreign Worthies, the manufactory at Etruria produces vases and urns in imitation of jasper and other variegated stones; a fine black porcelain, of which very beautiful vases and bas-reliefs are made, after antique patterns; Etruscan vases ornamented with encaustic paintings, after the antique; and bas-reliefs of a white composition, on coloured grounds, so as to have the effect of enlarged cameos. To

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ted many hundreds, to excite the humane to attend to and to assist in the abolition of the slave trade; and the other a cameo of Hope, attended by Peace and Art and Labour; which was made of argillaceous earth procured from Botany-Bay, to which place he sent many of them, to show what their materials were capable of, and to encourage the industry of the inhabitants.

[61] Accurate drawings of the various designs on the different parts of this curious vase may be seen in Darwin's *Botanic Garden*, part i. A very interesting story has also been written by Miss Edgeworth, founded on the circumstance of Mr. Wedgwood's imitation of this valuable piece of antiquity. It is entitled "The Prussian Vase," and will be found in the 1st volume of the *Moral Tales*. I mention this the rather because it contains a fine eulogium upon our inestimable trial by Jury.

the late Mr. Wedgwood the country is indebted for all these discoveries in the art of pottery.

Notwithstanding the energy with which Mr. Wedgwood devoted his inventive talents and chemical knowledge, to the improvement of his favourite manufacture, during the course of a long and industrious life, I have no doubt that chemistry might still confer many benefits on the potter's art, if the manufacturers in general would bestow such an education upon their children as would enable them to pay a proper attention to the cultivation of this science.

Impressed with this idea, I have myself frequently inspected several of the largest manufactories of earthenware in this kingdom, as well as many others of inferior note, and have examined their various processes with the utmost care and attention. A residence of several years at Stoke-upon-Trent, in the midst of the Staffordshire potteries, afforded me the best opportunities for this purpose, and enabled me to make those inquiries at my leisure, and to acquire that information which none but an inhabitant could easily have obtained.

It will not, however, be necessary for me, while giving an account of this manufactory as at present conducted, to go much into detail; because, if this were the object I had in view, it would be necessary to devote a volume or more to the purpose; for I am acquainted with few manufactories in which the operations are more numerous and diversified.

On this account, I shall content myself with giving

such an outline of the business as will afford the general reader a correct idea of the nature of the different operations; and at the same time shall propose, for the consideration of the manufacturers themselves, such hints for the improvement of some of the processes, as I conceive to be worth their attention.

Before I proceed to a descriptive detail of the several processes in the manufactory of earthenware, it will be proper to say a few words on the nature of the different materials which are usually employed to form the body of the ware itself.

It is well known that the chief ingredients are clay and flint; the former of which, when pure, is known to Chemists by the name of *alumina* and the latter by the name of *silica*; and that no kind of earthenware can ever be perfect, unless it be made of a suitable sort of clay[62], and in that proportion only which shall be correspondent to the quantity of flint employed. The experience of ages has confirmed this, and has proved that good pottery, as Vauquelin has remarked, differs from bad, less in the diversity of its elements, than in their proportions. How crude have been the notions of men respecting the chemical nature of bodies! The great Buffon "considered clay to be merely silica attenuated, and, as it were, rotted by the action of water, the air, and the sun."

Baumé was of opinion that sulphuric acid is a

[62] Macquer's Paper on Clays, in the *Memoirs of the Academy for the year* 1758, is highly deserving of perusal.

component part of all clays, and that the difference which is observable in different samples of this earth is chiefly owing to variation in the quantity of this acid—but this opinion is also erroneous.

There are four kinds of clay in common use in the Staffordshire potteries [63], and they are known by the following appellations, viz. *Black* clay, *Cracking* clay, *Brown* clay, and *Blue* clay. The two former are the produce of the south of Devonshire, the others are brought from the Isle of Purbeck in the county of Dorset. With regard to the price of these clays, that of the two first is 14*s*. per ton, delivered on board the vessel, or 44*s*. when delivered in the potteries. The price of the two latter is 21*s*. on board, or from 48*s*. to 52*s*. per ton, when delivered to the works.

The *black clay* takes its name from the colour which it usually bears, and this is derived from a quantity of bitumen or coaly matter which it contains. This carbonaceous portion is, however, entirely consumed when the clay passes through the potter's oven, for the articles made with it become when properly fired of a good white [64]. It is, indeed, a

[63] For the properties of the best porcelain clay consult the French *Chemical Dictionary*, article *Clay*, or Chaptal's *Chemistry applied to the Arts*, vol. iii. p. 225.

[64] The Roman potters must have learnt that the native clays differ very much in their nature and properties, for they had different names to distinguish them; such as *Argilla* for potter's clay; *Terra pinguis*, black clay; *Leucargillion*, white clay; *Terra sigillaris*, fine clay; and *Tasconium*, the clay for crucibles.

curious fact, that the blacker this clay is when it is first dug, the more white will the earthenware be which is made with it.

The second kind, called *cracking*, has acquired its name from a property which it has of occasioning the ware to crack during the first process of burning, or while making it into biscuit, if by accident a larger quantity than usual of it has been employed. But notwithstanding this singular property, the manufacturers are fond of it, on account of its extreme whiteness. It is, however, always dangerous to use it unless it be employed with judgement, because it has a peculiar tendency to crack even when mixed with the usual proportion of silica. Every kind of clay, when dried without any admixture, will be liable to this inconvenience; because, if *pure* argillaceous earth be made sufficiently soft to be modelled by the potter's wheel, it will shrink one inch in twelve during the process of drying, and this will inevitably produce the effect in question.

The third kind which I have mentioned, is what is known by the name of *brown clay*. The excellency of this sort is, that it burns white, without danger of its cracking like the last species, although it is liable to another imperfection which is termed *crazing*. Some manufacturers, however, employ this clay largely, while others, on account of this peculiar property, refuse it entirely.

CRAZING is a technical term to denote the cracking of the glaze. It is believed that this generally arises from a defective union of the glaze with the

body, owing to the clay, or the mixture of the clay with the other materials being ill calculated to receive the glaze properly. But may it not be occasioned rather by the glaze itself being not perfectly fusible? I suspect, however, that it more frequently originates from the circumstance of the ware being drawn out of the oven before it has time to cool gradually, and for the glass to become properly annealed. See the article *Annealing*, in the Essay on Glass in this volume. If lime be mixed with the materials which form the body of the ware, that will unavoidably occasion the crazing of the glaze.

The fourth kind, called *blue clay*, is considered to be the best, and, indeed, it always costs the highest price. This not only burns white, but it forms a very solid kind of ware, and will bear a larger proportion of flint than any other; and it is well known to potters, that the greater the quantity of silica, the whiter will be the earthenware; though if more of this species of earth should be employed than the clay will admit, it would occasion the goods to crack in the second burning. Both this and the brown clay are now much used for making porcelain [65].

It requires much practice to be enabled to understand the nature of clays sufficiently to employ them in pottery to the best advantage. Dr. Lewis,

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[65] An interesting enumeration of a variety of other uses to which clay may be applied, will be found in Fourcroy's *System of Chemistry*, vol. ii. p. 207.

in his Notes to Neumann's Chemistry, has given the results of many experiments on the mixture of clay with the different earths and earthy compounds for the purposes of making pottery, which may be read with advantage by those who are desirous of investigating this subject[66]. Chaptal speaks of a white earth from Ayoree in North America, which the French potters employ. Would not this be of equal value to our manufacturers?

Silica, or pure flint, as I have stated above, is likewise an important article in the manufacture of earthenware; forming, in general, a fourth, a fifth, or a sixth part of the whole of the bulk of the prepared mixture or paste, when taken by weight.

There is however one remarkable difference in the properties of silica and alumina, which has a very manifest effect on porcelain. Pure silica is transparent; but the thinnest lamina of alumina is entirely opake.

Alumina has such an affinity for silica that it will unite with it even in the humid way, and form a kind of mortar, which will harden by time, and be afterwards incapable of decomposition by the action of the atmosphere. This combination is the basis of many of the gems and precious stones.

Much of the flint used in England is brought from the neighbourhood of Larne in the county of Antrim, in Ireland; but as this comes out of a bed

[66] Lewis's Neumann, London, 1773, vol. i. p. 30, &c.

of limestone, it is not so good for the potter's use as the chalk flint. The price of the latter is at this time about 35*s*. per ton, delivered in the Staffordshire potteries. The flint which is most approved is procured chiefly from Gravesend, where it is found imbedded in the chalk [67]. It is usually sold at 40*s*. per ton, delivered at the works.

The English potters procure their flint on these low terms, because the people who are employed in Kent and the neighbouring counties in getting the limestone and chalk, are obliged to raise the flint also; which being in their way, the proprietors of the quarries are glad to ged rid of it even at a very inferior price.

It has been suggested by a friend of mine, that an inexhaustible source, for supplying the manufacturers with very excellent flint, would be the seashore; and that a person conversant with chemistry might readily examine a few samples of pebbles, and determine which were most suitable for making good pottery. On the coast of Sussex alone, particularly about Brighton, there is enough of *shingle*, as it is called, to serve the whole of the British empire for ages, and at no other cost than the carriage. Such, indeed, is the abundance and inconvenience of this natural production, that it would be worth while for the inhabitants of Brighton to give a small premium to encourage its exportation.

For making the finer kinds of earthenware a con-

[67] Silica is also a component part of various other stones, and is the basis of rock crystal, quartz, agate, &c.

siderable quantity of Cornish clay is also used, known commonly by the name of China-clay. This is the decomposed fel-spar of the granite; and it is prepared in Cornwall by the clay-merchants themselves, before it is transmitted to the Staffordshire potteries.

There are huge masses or rather mountains of white granite in Cornwall, and in some parts of the county this is found to be partially decomposed; and it is where this is the case, that the mineral is raised and prepared for the purpose of making earthenware and porcelain, it having been discovered some years ago, by Mr. Cookworthy of Plymouth, that this mineral furnishes us with the true *kaolin*, and also with the petuntse of the Chinese.

Granite is composed of quartz, fel-spar, and mica: and Mr. Gerhard found, in making an experiment on granite, that the fel-spar melted into a transparent glass; under it the mica lay in the form of a black slag, and the quartz remained unaltered[68].

To render the decomposing granite of Cornwall fit for the manufacturer, the following method is adopted. The stone is broken up by means of a pickaxe, and then thrown into a stream of running water. This washes off the light argillaceous parts and keeps them in suspension, whilst the quartz and the mica, thus separated, are allowed to subside near the place where the stone is first raised.

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[68] Nicholson's *Chemical Dictionary*.

At the end of these rivulets are a certain kind of catch-pools, where the water is at last arrested, and time is allowed for the pure clay, with which the water is thus charged, to separate entirely from it. As soon as all the clay has subsided, the water is drawn out of these receptacles. The solid matter is then dug up in square blocks, and laid on what are called *linnees*, which are several connected series of strong shelves, erected so as to allow of a proper circulation of air, in order that the clay may be more effectually dried for sale. It is then packed in casks and sent to the Staffordshire potteries, and elsewhere, under the name of China-clay. Thus prepared, it is extremely white, and in the state of an impalpable powder. It may here be observed that none of the native clays are entirely free from foreign ingredients. If pure argillaceous earth be required, it can only be procured from alum, which may be dissolved in water, and then decomposed by an alkali. In this process the pure clay will subside, which should then be thoroughly washed for use.

The price of these Cornish clays is considerably higher than that of any other kind; but for many of the finer purposes of pottery, they are absolutely indispensable. They are very smooth and ductile, and their extreme whiteness is very remarkable. It was analysed by Mr. Wedgwood, and found to consist of 60 parts alumina and 20 of silica.

The Cornish clay is also extremely useful for making crucibles, as it will not fuse by the addition of

any of the common fluxes. In using these crucibles, however, they should always be put within others which are of little value; the inner ones will then acquire the heat gradually, otherwise they would be in great danger of breaking.

Besides the clays already mentioned, some of the Cornish granite itself is often used with the clay on account of the binding quality which it possesses, and its knitting as it were the other materials more closely by its fusibility, it being naturally more fusible than the earths usually employed in this manufactory: for it is a curious fact, that neither clay, silica, nor lime, will melt singly; but by mixing these three species in due proportions the greatest degree of fusibility is acquired [69].

Having thus briefly described the several articles which are most commonly employed in making pottery, it will now be necessary to explain in what manner these are separately prepared for use.

The flints are managed in this way: they are first burnt in a kiln constructed for the purpose, and somewhat similar in form to a common lime-kiln; and then they are ground between very hard stones by a great power, which is given either by the water-wheel or by a steam-engine. In constructing the apparatus the purity and hardness of the stones are of very material consequence; for should

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[69] More on this subject may be seen, under the article *Clay*, in Macquer's *Additions to the French Chemical Dictionary*.

they contain calcareous earth, a portion of this would be abraded during the grinding of the flint, which would prove very detrimental to the pottery of which it formed a part.

To enable the operator to expedite the process, and at the same time to grind the flints finer, a quantity of water is thrown into the mill with them, so that the article, when finished, has much the appearance and the consistence of cream. The health of the workmen is also preserved by this expedient; for, before this method was adopted, the atmosphere of the room often became charged with the finer particles of the flint, which, entering into the lungs, sometimes produced the most disastrous consequences.

The grinding the flint with water was first practised by the celebrated Brindley, well known for his skill in the construction of inland canals. The mills now in use were also invented by him; and are composed of a very hard siliceous stone called chert, which is found in abundance in the neighbourhood of Bakewell in Derbyshire.

I have already hinted, that it is important to attend to the nature of the stone which is employed in these mills, and some years ago I was told of a very severe loss which was sustained by many of the large potters, in consequence of their having been supplied with great quantities of prepared flint which had been ground by stones containing a considerable portion of carbonate of lime, which being mixed with the flint, and eventually with the mate-

rial itself, occasioned to the body of manufacturers a loss of many thousand pounds.

In order to prepare the clay, it is first mixed with water to the consistence of cream: the design of this is, that it may be the more easily passed through the sieves, and intimately united with the ground flint, which could not be done with uniformity and certainty if these earths were mixed dry.

The mixture of the clay and water in the first instance, is generally effected by means of long wooden instruments, which the men move backwards and forwards with considerable force throughout the whole mass. It is an operation of great labour, and is distinguished by the term *blunging*.

The ground flint is mixed in a similar way with water, and the stirring is continued until it become one uniform fluid mass. But these earths, the clay and the flint, are always blunged *separately*; because, if otherwise, and the two earths were mixed before being deprived of their impurities, which cannot be done till they are brought into a fluid state, it would be impossible to observe the requisite proportions of each.

The Purification of these earths is effected by a process similar to that which the chemist calls Elutriation. When the earth has been well broken and thoroughly mixed with water, it is put into vats, or other large vessels; and when it has stood long enough for the grosser parts to subside, the fluid containing the finer particles is drawn off by a plug, and reserved for use.

In every preparation of these materials for the formation of earthenware or porcelain, it is of the utmost consequence to attend to the relative quantities of each: therefore, whenever these mixtures of the fluid clay with the flint are to be made, they are always done with some nicety, an attention being paid to the specific gravity of each of the fluids, which is either made heavier, or diluted further with water, as the case may require. The mixture of clay and water after it has passed *once* through the sieve, is generally brought to the specific gravity of 24 oz. the wine pint. A pint measure of the ground flint and water, when in the same state, is usually 32 ounces.

When the clay and the flint are mixed in suitable proportions, the whole mass, in this state of semifluidity, is passed through the sieves to take out any remaining impurities, and also to detain those particles which have not been sufficiently levigated. The mixture is then passed through the finest silk lawn, to ensure the certainty of no unbroken pieces remaining in it, and to reduce the whole to a state of the utmost uniformity and smoothness [67].

The next object is, to separate the water which has been employed with such profusion, and the readiest way of effecting this is found to be by the direct application of heat. The mass is therefore now poured into very long brick troughs, which

[67] A curious account of the Spanish method of preparing the clay for making the alcarazas, or wine-coolers, may be seen in a Memoir by Lasteyrie, in the *Journal des Mines* for 1798.

are built with flues under them of a sufficient size to afford heat enough to produce an ebullition in the mixture; and this is continued until so much of the water is evaporated as will reduce the mass to the desired consistence.

The evaporation is, indeed, never carried beyond a certain point; because, if this mixture of the earths were allowed to become nearly dry, it would not be kneadable by the usual methods; neither could it be worked, by the hand or the wheel, into any of those forms which it may be the intention or the interest of the potter to impart to it.

I ought to have mentioned, that the mixture of the clay and the flint with water, is known in the trade by the name of *slip*; that the place in which it is kept is the *slip-house*; and the trough on which it is boiled is called the *slip-kiln*.

When the mixture has been thus brought to a proper consistence, it ought to be kept for a considerable time, that the materials may become more intimately united than they can ever be by mere mechanical force: but, in general, this is not much attended to, although every manufacturer is fully aware of its importance. Want of room, of time, and often of capital, occasions it to be sometimes used warm from the slip-kiln, and not uncommonly when it has been lying for only a few hours or days. In China it is no unusual thing for the prepared clay to remain from 14 to 20 years before it is thought to be in a fit state for use; and I have heard of some districts where it is custo-

mary for a father to prepare as much porcelain-clay as will be sufficient for the use of his son throughout the whole period of his life.

When the dried mass has been removed from the kiln, the next process is that of tempering it, which is effected by first beating it with mallets, and then turning it and beating it again, and again, with small spades, or paddles, as the workmen call them, until it is thought to be as well tempered as it can be by these operations.

It should be recollected that this is not pure clay, but a mixture of all the ingredients. Vauquelin says that "Silex constantly forms at least two-thirds of most pottery; alumine from a fifth to one-third; lime from one five-hundredth to one twenty-hundredth part; and iron from the minutest quantity to twelve or fifteen per cent."

The mass, after the operation of beating, undergoes a process called *slapping*. For this purpose it is removed, in the state of large lumps, to a convenient bench or table, where a man having cut it across with a brass wire, unites it again by slapping one of the halves down upon the other with all his force; he then cross-cuts it again and again, and as often unites it by main force, as before.

This cutting the clay in pieces and slapping it together, is a laborious operation; but it must always be continued until the air-bubbles, which the mass at first contained in great abundance, are all driven out of it; because, if the air was not thus carefully expelled from the clay, it would escape

when it became rarified in the oven, and this would produce such blisters as would spoil the manufactured goods. On this account the slapping is continued until the mass exhibits, wherever it may be cut, a perfectly smooth and homogeneous surface.

Of late years Mr. Wedgwood and some other considerable potters have, however, employed an apparatus invented by Mr. Thomas Lowe of Nottingham, which effects all these purposes at once. It is moved by a steam-engine, and performs all these operations with a surprising economy of time and labour. It first breaks the burnt flint; it then grinds it in water, and another part of the apparatus performs the hitherto laborious operation of blunging[68] the clay in water and breaking it into a semi-fluid and uniform mass. When this is done, it is run off and sifted by several sieves of different degrees of fineness, all which are moved by the same power. This earthy fluid then runs down to a lower room, where it goes through other sieves in the same way. In like manner, another part of the apparatus squeezes the dried clay, to save the expensive operation of *slapping*, described at page 116; after which it passes to an iron cylinder full of knives, where it is cut into pieces with great expedition; which saves the expense of cutting it by hand with brass wires, as before mentioned. This receptacle is not properly a cylinder, but a large hollow inverted cone of iron, and the knives are fixed in an upright

[68] This is the technical term, but doubtless it is a corruption of the word *plunging*.

shaft which revolves within it and passes through its centre. These knives are so contrived that the clay, as it is cut, is forced lower and lower by every revolution, until at last it is pressed by the power of the machinery through a square hole near the bottom of the apparatus, from whence it is removed as it falls, and is carried in blocks to the other parts of the manufactory.

The clay having undergone these varied operations, it is now fit for being formed into any shape, or employed for any purpose, for which it is designed. Accordingly, it is fashioned into various forms by means of a variety of moulds made of plaster of Paris; or put into as great a diversity of shapes by the potter's wheel.

Nothing is found to answer so well for making the potter's moulds as plaster of Paris; because, when right prepared, it has the property of absorbing the water so very rapidly from the ware, that it occasions it to slip out of the mould, or to *deliver* itself easily, as the technical phrase is.

To prepare the plaster for making the moulds, it is first ground in a mill exactly similar to that which is generally used for grinding corn by means of a pair of flour stones; it is then baked, or rather boiled [69], to expell the water which is one of its component parts when in a native state.

[69] *Boiled.* This may appear to be an incongruous expression when applied to a dry earthy substance; but the fact is, that when the ground plaster is heated it has so much the appear-

This plaster, which is the native sulphate of lime, is boiled in very long brick troughs, having a fire flue running underneath them. The man who superintends the process has a handkerchief tied over his mouth for safety; as the small particles getting upon the lungs, or into the stomach, have been found to be very injurious to the health of the operator.

When this plaster has been thus deprived of water, it is in the state of a soft and impalpable powder; and if its own proportion of water be again mixed with it, it will immediately set into a hard compact mass. It is this property which renders it so peculiarly fit for making the potter's moulds.

The manipulations by which the different articles of earthenware are made, are so various and multiplied, that it would be very difficult, if not impossible, to describe them. They can be known only by those who have had opportunities of visiting a pottery. A short outline of these processes will however be expected from me, and may be acceptable to the generality of my readers.

Much of the common earthenware is formed by means of the potter's wheel, which is a round board attached to a lathe, and capable of being moved thereby, either rapidly or otherwise, as the occasion may require. This round board moves in a horizon-

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ance of ebullition, that the term which I have employed is made use of by the workmen universally. The finished article is always called *boiled plaster*.

tal position; and when in use, the clay which is to be fashioned is fixed on the centre of it; and it is put in motion either by a person who constantly attends it when at work, or by means of a treadle which is moved by the foot of the workman himself.

As the clay revolves upon this machine, the workman either models it by his fingers, or forms it, by means of an instrument which he holds in his hand, into any kind of circular shape that he may desire; and when the object is to make a number of vessels exactly similar to each other, the size is generally determined by a gauge fixed without the circumference of the revolving wheel, but projecting over it in such a manner that, whenever the yielding clay is spread out until it touch this gauge, the artist knows that the article which he is making has attained the exact figure which he intends.

The potter's wheel is probably the most ancient of the manufacturing instruments now in use. It was known to the author of that book in the Jewish Scriptures, which claims the highest antiquity of any writings we have, and who must have lived at least 3000 years ago. This simple instrument has however of late years been much improved by adapting a strap to it, which passes over a large taper cylinder of wood, by means of which the artist is enabled to increase or diminish the rapidity of the motion at pleasure. This contrivance is known to mechanics by the name of the *cone pulley*.

In going through a pottery, it will be observed,

that all the articles are very thick and coarse when they come from the wheel. This is perhaps unavoidable. They are therefore taken to a lathe, where the extra quantity of clay is removed, in the same manner as the wood-turner forms his work by shaving off successive portions of the wood. These parings of clay are afterwards kneaded as before, and then worked over again for similar purposes.

It is curious to notice the great variety of circular things that may thus be made by means of the potter's wheel; but it must be remembered that this machine is calculated only for cylindrical, conical, or round articles, and not for such as are of an oval or an irregular form. All such are made in plaster moulds, which divide in halves for the convenience of taking out the ware whenever it is found to be sufficiently dry to be removed. The handles of cups and jugs are also made in moulds, and these are afterwards put on the vessels for which they were designed.

The consumption of sulphate of lime, gypsum, or alabaster, (for this substance is known by these various names,) is so considerable for making the moulds for plates and dishes, that in the course of the year many tons of worn out moulds are thrown away as useless. I would suggest, that these might be ground and used as manure, instead of purchasing fresh gypsum for that purpose.

As the plaster moulds absorb water with avidity, the articles which are made in them dry much

sooner than would generally be imagined. For instance, the moulds on which the common table-plates are formed, are put into a very temperate stove as the plates are made, and in about two hours the whole will be dry enough to be removed to make room for a fresh parcel. In the usual way of conducting a manufactory, every mould is capable of taking four or five fresh plates in the course of a day of twelve hours. The plate-stove is generally a very small room built with bricks, and shelved with boards from the floor to the ceiling. It is usually heated by an iron pipe which passes through it.

When the plates are removed from this stove, they are taken off the moulds, and pared round the edges with a small knife; and when they have been slightly polished by the hand, they are laid by to become hard enough for the biscuit oven.

From this short account it may be easily conceived that a common-sized pottery must require a great deal of room, especially as every article, whether made by the wheel, the lathe, or the moulds, must be spread out upon shelves to dry: and this reminds me of an expedient which I lately observed at the works of an ingenious potter in Staffordshire, and which I conceive to be so far an improvement upon the old practice, as to deserve being mentioned, and which I have the leave of the proprietor to make public.

The improvement to which I refer, is that of having a chamber shelved entirely round, not with stones or boards as is usual, but with shelves of

prepared plaster made as smooth as polished marble, and of the thickness of an inch and a half each.

Upon these plaster shelves, instead of those of wood and stone as commonly adopted at other works, the goods are placed to dry: and the great advantage which must accrue to the manufacturer from the practice is very obvious; for the plaster not only absorbs the water sooner, but the articles will dry more regularly and uniformly than they possibly can when placed upon substances which cannot abstract the water. Being persuaded of the utility of this expedient, I have no hesitation in recommending it for general imitation. Moreover, why may not the floors of a potter's warehouses be covered with plaster? The expense would be very inconsiderable, and then, whenever these were not in use for storing the finished ware, they might be advantageously employed in hastening the drying of the goods newly made.

In some counties it is usual to form the floors of cheese chambers with plaster, and I have been told that the cheese becomes sooner ripe on these floors than on others; though Mr. Twamley directs that it should not be placed on plaster until time has been allowed for the first moisture to exude and evaporate [70].

An important improvement might be made in the manufacture of earthenware, if it were possible

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[70] Josiah Twamley *On Dairying*, 8vo, Warwick, 1784, p. 100.

to contrive an expeditious mode of spreading the goods out so as they might always dry gradually. The property which clay has of contracting by heat or by drying is well known, and the excellence of earthenware depends in a great measure on its being very *gradually* dried before it be exposed to the kiln.

When the articles of pottery have been modelled or fashioned to the design of the artist by any of the foregoing methods, and have been partially dried, either by an exposure to the action of the atmosphere, or by placing them for a certain time in stoves or drying rooms coustructed for the purpose, they are carried to the potter's oven, where they are placed in deep oval boxes made of fire clay. These are called *seggars*; anp being flat at bottom, one of these vessels forms a cover for another, so that the workmen are enabled without difficulty to place them in piles nearly to the top of the oven, which is a large building of brick, in the form of a cone, and very similar to a common glass-house.

When the oven is properly filled, heat is applied by means of ignited coal, which is thrown into several receptacles built on the outside, but communicating, by means of flues, with the inner part. These are called *mouths*; they stand about four feet in height from the ground, and project about three feet from the sides of the kiln.

In the beginning the heat is kept at a low state; but after a lapse of twelve hours it is gradually increased, and the augmentation of temperature is

continued until the kiln and its contents acquire the proper maximum.

An attention to the degree of baking is an object of extreme importance. Vauquelin has remarked that "the heat should be such as to expel the moisture, and agglutinate the parts which enter into the composition of the paste; but incapable of effecting the fusion, which, if too far advanced, will render the ware of so homogeneous a texture as to become brittle[71]."

It has been found that alumina loses 0.46 of its weight even when the fire is not urged beyond the temperature of ignition for silver; whence it appears that it contains nearly half its weight of water, and it does not part with the last portion but with great difficulty.

The operation of burning usually lasts two days and two nights. This, however, varies in the different charges; and the fireman judges when the ware is sufficiently burnt, by examining the trial pieces which are placed in those parts of the oven where they may be taken out with ease, and without causing any diminution of the heat.

These trial pieces are made of the common red clay, of the Staffordshire brick-makers. It is found in the Potteries, and has the property of changing its colour at every change of temperature: therefore, by comparing one of these, taken out of each

[71] Vauquelin's *Reflections on the Qualities of Pottery*, communicated to the Philomathic Society at Paris.

part of the oven, with a trial piece made of the same kind of clay and properly burnt, and which is kept on purpose for a standard, the exact state of the ware under operation may at any time be exactly known.

All the common ware undergoes two firings: that is, when it has been sufficiently dried in the air, it is put into an oven and made into what is called *biscuit*, which is earthenware partially burnt.

Many ladies are in the habit of buying china in the state of biscuit, for the purposes of painting and gilding. When they have imparted their own designs, these are sometimes returned to the potter, who burnishes the gold and completes the baking. This is mentioned with the view of directing those females who may not be already acquainted with it, to a new object for the exercise of their taste and genius, and also for the better explanation of the nature of biscuit ware.

All the English earthenware and china undergoes this previous firing, because, were it not first made into *biscuit*, it would not bear to be immersed in the mixture of lead and water, called the glaze, without suffering injury thereby: that is, it would not fail to be rendered soft, and liable to be put out of form, by its absorption of the water. Neither would it sustain the process of printing, nor allow of its being painted upon with any good effect.

The composition of the Chinese porcelain is different, and its nature is now pretty accurately known. Mr. John Bradley Blake, who was settled as a resi-

dent Supercargo at Canton, and died there at the age of 29, sent, a short time before his death, to Mr. Samuel Moore, the then Secretary to the Society for the Promotion of the Arts, specimens of the earths, clays, sand, stones, and other materials used in making the true Nankin porcelain, all which Mr. Moore put into the hands of the late Mr. Wedgwood, who from these materials produced some pieces of excellent porcelain, and declared that those earths were so complete a set of specimens, that he had no doubt of their being the true materials of the Oriental porcelain. Had Mr. Blake lived, further information would have been procured.

It was ascertained by Mr. Blake, and we have learnt from other sources, that in China the earthenware and porcelain are merely dried in the air before glazing; as their composition so effectually resists water, that it can be immersed in an aqueous glaze, without being first made into biscuit, and consequently that the Chinese are enabled to burn their ware by one single firing.

It is therefore a desideratum with the potters of this country, to find some substance to mix with the clay which shall give it the property of resisting the action of water before it has undergone the first burning. This would be a great acquisition to our English manufacturers, because it would not only be a saving of fuel, but a great economy of time and of the expense of wages, as one operation would be thereby entirely saved.

Dr. Woodward mentions the Soap Rock at the

Lizard Point, and the steatites in other places, as very likely to make good porcelain[72]. Dr. Campbell also, who seems to understand this subject, strongly recommends this article to be employed in the manufacture of china[73]. Whether steatites will improve the body of the ware, as above mentioned, I do not know, but I know it has been used at some of our porcelain works in considerable quantities.

Should the English potter be able to make the body of his ware equal to that of the East, it would then be necessary, as I apprehend, to discover some other material for the glaze; because, if our ware were burnt, as it is in China, by one operation, the earth would contract more than the glaze, and consequently the latter must either crack, or partially fly off.

I hazard this opinion, because I know that in China the glaze is infinitely better than ours, inasmuch as it consists purely of fel-spar, and is so extremely hard that it cannot be operated upon by any of our common cutting instruments. Even the wheel of the glass-grinder will not touch it; whereas ours becomes scratched and defaced by common usage and ordinary wear[74].

If the glaze on porcelain be too thick, this will occasion it to break; it is therefore important to ap-

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[72] Woodward's *History of Fossils*, vol. i. page 6.

[73] *Political Survey of Great Britain*, vol. ii. page 19.

[74] This remark is not applicable to all the European porcelain; for that made in Saxony, and in some other parts of Germany, is equal to the best Oriental china.

ply a thin glaze, the fusibility of which should be as nearly as possible approaching to that of the body of the ware, in order that the combination may be more intimate and lasting. Chaptal describes a glaze which perhaps our potters may imitate with advantage. "It consists," says he, "in mixing the earth of Murviel in water, and dipping the pottery therein. When dry, they are plunged into a second water, in which levigated green glass is mixed. This covering of vitreous powder fuses with the clay of Murviel, and the result is a very smooth, very white, and very cheap glazing [75].

The great durability of the Oriental china is its main excellence. We make porcelain in this country which is equally beautiful; and, if the symmetry of the figures and the merit of the painting be considered, far more elegant, although it possesses a less degree of tenacity and hardness [76]. We have, indeed, lately noticed the introduction of what is called stone-china, which is made very thick and clumsy to imitate some of the best productions of the East: the glaze upon this, however, is as poor and soft as upon other English china.

Is it not natural then to ask, Why do not our

[75] Chaptal's *Elements of Chemistry*, English Transl., vol. ii. page 88.

[76] It is probable that the heaviest and most compact china will always prove to be the most durable. Dr. Watson, in taking the specific gravity of several specimens of pottery, found that a cubic foot of cream-coloured ware weighed 1988 ounces avoirdupois; of flint ware, 2188 ounces; of Bristol stone ware, 2340 ounces; and of East Indian china, 2346 ounces.

potters make use of a better glaze [77], especially as the county of Cornwall can furnish felspar in abundance and at a reasonable price?

The true answer to this question seems to be this: that our ovens are not capable of fusing a glaze similar to that which is employed in China [78]. The heat of the potter's oven in that country must be tremendous. The materials could not be vitrified as we see them, with less heat than would fuse Cornish granite.

An ingenious mode of discovering when the glaze on china is not sufficiently hard, has been giving by the late Mr. Nicholson. It consists in dropping a small quantity of strong ink upon it, drying this before the fire, and then washing it. If the glaze be too soft, an indelible brown stain will remain upon it. [77]

It must here be remarked, that for those who choose to incur the expense, there is porcelain manufactured in some parts of this kingdom which is more durable than that commonly made in the

[77] In the year 1803, Professor Proust, of Madrid, published some remarks on the glazes of pottery. See his paper in the *Journal de Physique*, under the title of "A Memoir on tinning Copper Vessels." Extracts from this production will be found in the *Philosophical Magazine*, vol. xxi. p. 313.

[78] The fusibility of the earthy compounds depends upon their proportions. Lime and clay are separately infusible; but, in due proportions, the mixture is capable of forming a perfect glass.

[79] *Chemical Dictionary*, article *Pottery*, 8vo, London, 1808.

[80] Campbell's *Political Survey of Great Britain*, vol. ii. p. 18.

[81] Dresden china was formerly in such high estimation in this country, that in the year 1763 a single service of it was sold by auction in London, at Mr. Uhthoff's sale, for 115 pounds. *Gentleman's Magaz.* vol. xxxiii. p. 312.

Staffordshire potteries. Such was formerly the Bow china, and that also made at Chelsea [80]; and I have been credibly informed, the china now manufactured at Worcester is nearly equal to the best Dresden [81], or to the true Nankin, in all those properties which give the most value to this production of art.

It is worthy of observation, that while the King of Prussia was pursuing every possible method of advancing and extending the manufactory at Berlin [82], the works at Worcester continued to improve year after year, without patronage, and that they were brought to their present perfection solely by the genius and enterprise of the proprietors.

Of late years a porcelain manufactory of considerable consequence has been established at Coalport in the county of Salop. Some peculiar kinds of China, both serviceable and beautiful, are produced at these works.

The common heat of the potter's kiln in England is about 60° of Wedgwood's pyrometer [83], which is equal to 8·877 degrees of Fahrenheit for

[80] In order to encourage this manufactory, and make its productions more generally known, the King made presents of complete services of the Dresden porcelain to all the sovereign princes in Germany.

[83] For an account of the construction of Wedgwood's pyrometer the reader is referred to the lxxiid and several of the subsequent volumes of the *Philosophical Transactions*, or to Murray's *System of Chemistry*, vol. i. p. 150. The pieces of baked earth which he employed for the pyrometers were analysed by Vauquelin, who states them to have consisted of silica 64, alumina 25, charcoal 6, oxide of iron 0·2, water 6·2. Nicholson's 4to *Journal*, vol. iii. p. 265.

the cheapest cream-coloured ware, and about 80° of Wedgwood for the Staffordshire porcelain; though I have reason to believe that the manufacturers of the best cream-coloured ware seldom allow the heat of the kiln to exceed 45° of Wedgwood's pyrometer. It must be recollected, however, that we fire twice, and that these heats refer to what are employed in converting the ware into what is called biscuit.

I am not myself acquainted with the respective temperatures at which the other porcelain manufacturers fire their ware; but Dr. Henry has stated that the Worcester china vitrifies at 94, that the Chelsea porcelain is fired at 105, and the Derby at 112 of Wedgwood.

In the Staffordshire potteries the temperature of the gloss-oven is generally about 10° of Wedgwood, or 2·377 degrees less of Fahrenheit than the heat of the biscuit oven. The reason of this is, that there may never be any danger of the ware, in this last operation, undergoing a higher degree of heat than it experienced in the first burning; it being absolutely necessary for the operator to be careful of this point, because, as clay will continue to contract by every addition of heat, it must follow, that should it ever be pushed beyond that degree which it sustained in the state of biscuit, the body of the ware would experience a greater contraction, and consequently every piece within the oven would either become crooked, or the glaze would be injured. The firing of the gloss-oven generally requires from 12 to 14 hours.

The glazing for the common cream-coloured earthenware consists usually of certain portions of litharge of lead and ground flints, mixed with as much water as will form them to the consistence of thin cream, which is found to be a state the most suitable for the immersion of the ware. One hundred pounds of litharge and 40 pounds of ground flints are the common proportions; but it is usual to take 80 pounds of Cornish granite to 100 pounds of litharge, whenever that is used instead of flints. Flint is the article which is employed in making glaze for the porcelain as well as for the coarse earthenware, it being nearly all silica. Klaproth found common flint to consist of ignited silica 98 parts, lime 0·50, alumina 0·25, ignited oxide of iron 0·25 parts, volatile in the fire, 1.[84]

For the finer kinds of earthenware and for porcelain, it is made with white lead, ground flint glass, ground silica, and common salt. Some manufacturers, however, add other materials; most of those who superintend this department imagining that they possess a valuable secret, and that in consequence of it their glaze is much better or cheaper than that of others.

In all manufactories it is found necessary to vary the composition of the glaze, according to the nature of the materials which form the body of the ware; and the former cannot be perfect unless it be

[84] Klaproth's *Analytical Essays*, vol. i. p. 42.

capable of contracting and expanding by heat and cold, in the same proportion as the ware itself will contract or expand by change of temperature. The writer of the article Porcelain in the French Chemical Dictionary very properly remarks that "a glass which makes a fine glazing for one porcelain, will make a very bad glazing for another sort of porcelain, will crack in many places, and have no lustre. The glazing must be appropriated to the density of the ware and the ingredients of its composition."

As the number of potters has increased very much within the last 50 years, the competition has become so great that every manufacturer is under the necessity of consulting economy, and of sometimes sacrificing the utility and goodness of the ware, for the sake either of appearances or of adopting the cheapest modes of manufacture that can be devised.

To one of these causes, may be attributed the introduction of *bones* into the manufacture of porcelain. Of this article there is now so large a consumption in the Staffordshire potteries, that some of the great manufacturers have extensive rooms which are used solely for the reception of bones. Animal bones are composed of lime and phosphoric acid, in different proportions according to the age and species of the respective animals to which they belonged. These are either bought of the indigent bone-collectors in the country, and then burnt and ground by the potter, or they are purchased ready

burnt and ground for use, directly from those who distill volatile alkali or spirit of hartshorn. It is, however, generally known to the china manufacturers, that this article is injurious to the texture of the ware: its use, therefore, cannot be justified on any account whatever.

I allow that ground bones have the effect of rendering the goods very white, and also that they produce a transparent appearance; but I doubt whether this be a real transparency, or only a deception. Thus far, however, one may venture to assert, that the modern English porcelain, which has the usual proportion of bones in its composition, is of much less specific gravity than it ought to be[85], and is very apt to crack with hot water. As the base of animal bones is phosphate of lime, it might be worth while for the potter who is determined to use bones, to try whether the *native* phosphate of lime[86] can be useful in making porcelain, and if phosphate of alumina may also be employed in this manufacture.

In returning to the subject of glazing, it will be proper to state that the common earthenware would be too porous, and many kinds of fluids would pass

[85] For the specific gravity of good porcelain, see Note 76, page 129.

[86] A memoir by Hassenfratz "On the native phosphate of lime" may be seen in the *Annales de Chimie*, tome i. page 191. Likewise some "Remarks on phosphate of alumina and on a mountain of calcareous phosphate," by Proust, in the same volume, page 196.

through it, were it not defended by an artificial covering or permanent glaze. It became necessary therefore to contrive a composition which should vitrify and flow in the fire, so as to cover these materials of earth with an entire coating of perfect glass.

Such a glaze having been found in a mixture of oxide of lead [87] and silica [88], as mentioned above, a certain proportion of each of these, ground to an impalpable powder, is thrown into a tub of water, and stirred therein till the mixed powder becomes suspended and uniformly dispersed throughout the fluid.

The glaze having been thus prepared, it is applied to the ware in the following manner. A workman to whom this duty belongs, receives the goods from a boy, who delivers them to him one at a time; and as he receives each single piece, he dips it in the liquid, lets it drain for a moment, and then, placing it on a board standing beside him, he is ready to receive another piece, which he immerses in like manner.

It is in this way that the glaze is applied to all the various articles which are made of the common earthenware; and as it is only partially baked or in the state of biscuit, when it is immersed in the glaze,

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[87] The French potters, instead of an oxide of lead, use the common galena or sulphuret of lead for this purpose.

[88] Silica was formerly known by the name of the *vitrifiable* earth, because mixed with an alkali it possesses the property of fusing into a transparent glass.

a sufficient quantity attaches itself to the surface, which, when it has been fused, will form over it a complete covering of glass. This mixture has great fusibility, though silica alone does not melt in the focus of the most powerful burning mirror. Mr. Hare, however, fused it completely by submitting it to the flame of a stream of mixed oxygen and hydrogen gases, and found that it formed when cold a kind of enamel [89].

There are, however, strong objections to this mode of glazing pottery. The men who work in it for a considerable time are apt to become paralytic, probably from the lead [90]; and where acids, which have the power of dissolving the lead, are employed in preparing condiments for our food, such a glaze must be extremely unwholesome.

Aware of the pernicious effects of lead, when taken into the stomach, M. Fourmy, an ingenious manufacturer at Paris, has prepared water-coolers, in which he has employed lava for the glaze, instead of the deleterious metallic covering which is more commonly used for that purpose. Pumice-stone has also, as I understand, been used for covering earthenware, and with very good effect.

Some of the French potters, at the suggestion of Chaptal, have substituted common flint glass for lead in their glazing, and have found it not only

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[89] *Philosophical Magazine*, vol. xiv. p. 304.

[90] Some directions for the prevention of this malady will be found in *The Chemical Catechism*, tenth Edition, p. 101.

safer, but more economical. They grind broken flint glass to a fine powder; and when this is mixed with a due portion of clay and water, the goods are dipped into it, as our potters dip their ware.

The potters of Bristol and Lambeth glaze their stone ware with common salt. When the oven has acquired a certain temperature, the salt is cast in, and the vapours arising from it attach themselves to the goods, and completely cover them. The alkali of the salt probably combines with the silica of the ware, and forms a true glass upon their surfaces.

The English potters are however fond of using a glaze made with lead and silica, because, whatever the articles may be which are employed for this purpose, it is necessary to give them a heat sufficient to vitrify the materials and convert them into a perfect glass; and when the best articles are made use of in forming a glaze, the heat which is employed must be very considerable; whereas lead alone will readily fuse and form a glaze that may be finished at a very low heat indeed. This, however, if used alone, would make a glaze too soft, and so extremely fusible that it would be apt to run very much towards the lower parts of the ware, and leave the upper ones imperfectly covered.

Half a century ago our potters were so careless in their manner of applying the salt glaze to the stone wares of Staffordshire, that large importations were made from France and Holland, where the manufacture was better conducted; and had it not

been for Mr. Wedgwood's timely invention of the Queen's ware, it is probable that the best part of the trade would long ago have been lost to this country.

A variety is sometimes given to the glaze by mixing certain oxides of the metals, especially that of copper, or otherwise the filings of copper; but this coloured glaze is generally applied only partially, and merely for goods of inferior quality. The edges of common plates are sometimes coloured by this method. [91]

It is about sixty years since the plain cream-coloured ware of Mr. Wedgwood was introduced. At that time this unadorned and simple article was thought sufficient for every purpose where porcelain was not employed; and the neatness and cleanliness of its appearance gave it such a decided preference that her late Majesty allowed the worthy inventor to call it *Queen's-ware*; but, when a demand arose for more expensive services of pottery, recourse was had to the pencil. From that period a great number of artists have been constantly employed in painting earthenware as well as porcelain, and often great taste is displayed in these productions.

It must not however be imagined that painting on earthenware was a new invention. The paint-

[91] The beautiful black glaze, which is seen on a peculiar sort of ware made at Nottingham, is composed of 21 parts by weight of white lead, 5 of flints, and 3 of the oxide of manganese. Watson's *Chemical Essays*, vol. ii. page 271.

ings of the ancients of this kind are rare and valuable. The Marquis Marcello Venuti, in his description of the curiosities found in the ancient city of Heraclea, speaks of one upon *slate*, representing a muse crowned with laurel, with a musical instrument hanging on her shoulders, which was found in one of the subterraneous cavities, and is described as being then in the possession of Signor Nicolo Vagnucci of Cortona, one of the principal supporters of the Academy of Tuscany [92].

Nevertheless, it must not be concealed that Chaptal has shown, that the Romans of the first century were not acquainted with any of the metallic fluxes with which the moderns fix and vitrify the coverings of their pottery. For the particulars consult his very instructive account of certain colours which were found in the shop of a colour-merchant in one of the streets of the ancient Pompeia, especially as he has there told us what was the composition of the glaze which the potters of that day did actually employ [93].

To return to the consideration of the paintings on English earthenware, it must be observed that the variety of effect is produced by means of the different metallic oxides, each of which affords a different colour, and these colours are again multiplied by such mixtures of two or more of the oxidized metals, as experience has shown to be useful.

In employing these various colours, the ground

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[92] Skurray's *Translation*, 8vo, London, 1750, page 107.
[93] *Annales de Chimie*, tome lxx, p. 22.

oxide is first mixed with a prepared flux, which is also reduced to an impalpable powder, and then this mixture is well incorporated with gum water, the acid of tar, oil of turpentine, or some other essential oil, as may be most suitable, in point of expense or otherwise, for the goods on which it is to be employed. The fluids are used merely to lay on the colour; for it is necessary that, whatever oil be employed, it should have the property of evaporating entirely.

The preparations which are commonly used, are the metallic oxides and their combinations with acids. Thus cobalt yields a blue; antimony and silver give yellows and oranges; platinum a silver colour[94]; gold violet and purple; copper the greens; while the reds, the browns, and the blacks, are derived from iron.

The oxide of cobalt employed in the pottery is usually prepared from zaffre, which is an expensive article imported from Saxony, though a few years ago very fine oxide of cobalt was procured from Cornwall; for preparing antimonial yellows, the crude antimony is first calcined with four times its weight of nitre, and is then mixed with a certain proportion of vitrified lead. The precipitate of Cassius is the article which is generally used for the production of violets and purples, though sometimes

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[94] Some observations by Klaproth on the uses of platinum in pottery, may be seen in the *Phil. Mag.* vol. xvii. p. 135.

the oxide of gold precipated by copper is employed. For greens, the copper has usually been taken in the state of a precipitate; but some potters have found an article of more value in the pure oxide of copper, which they procure by placing sheets of copper in the ovens in which the ware is glazed: and it has lately been discovered that a small portion of copper mixed with the iron very much increases the intensity of the blacks on earthenware. Besides, iron itself is capable of giving a great variety of colours, according to the way in which it is managed. For instance, the black oxide of this metal produced by the action of heated air only, will be a very different article when used as a pigment from an oxide of iron prepared by other means.

It is here necessary to remark, that in painting on the biscuit no oil is used; the metallic oxides are mixed with water only; and it is owing to this circumstance that such ware may be glazed at once without being put into an oven, as is the case with those goods which are known by the appellation of *blue-printed*.

For certain purposes, however, the painting is performed *upon* the glaze, as some colours would be injured, and others destroyed, by the heat of the gloss-oven. Thus, where iron is employed to produce blacks or browns, the painting is always done *upon* the glaze; the ware is then finished in an enamel-oven, at about 6° of Wedgwood's pyrometer.

Some metallic oxides are used for another intention besides that of painting, viz. for the purpose of

covering the ware entirely on the exterior, as is the case when the sulphuret of antimony is employed for producing a common kind of yellow ware; and also for those articles known by the names of GOLD and SILVER LUSTRE. The first of these lustres is effected by means of gold, the latter by the oxide of platinum. For gilding porcelain the metal is used in its metallic state. To procure it in a pulverized form, it is dissolved in aqua regia, and then the acid is driven off by heat, and the gold remains; this is then mixed with borax and gum-water, which form together a proper vehicle for fixing it upon the goods. After this it is baked, and finished by burnishing.

For preparing the lustre ware, as it is called, the oxide, of whatever kind it may be, is mixed with some one of the essential oils, and in that state it is brushed upon the surface of the articles. It should have been observed, that when the manufacturer intends to make lustre-ware, the articles are glazed *before* the gold or the platinum is applied. For *gold*-lustre, the ware is made of a red clay, which, when burnt and glazed, shows so much of its colour through the covering of gold, as is sufficient to give the goods that peculiar brown tint which is always observable on this singular kind of pottery.

When the metallic oxide has been properly applied to the surface of the goods, they are carried to an enamelling-oven, where the heat dissipates the oxygen, and restores these precious metals to their metallic state,—I cannot say quite to their primitive metallic brilliancy, because this is often much

injured by the fluid menstruum employed in the operation. The great difference which there is in the appearance of this ware, especially in that which is covered with platinum, can only be thus accounted for. Some of it looks like silver, while the articles from other manufactories are more like iron or steel.

I once imagined that this variation might arise from a different mode of preparing the oxide of platinum. I therefore prepared two samples of this oxide, the one precipitated by caustic ammonia, and the other by muriate of ammonia; but, when I had them tried by an experienced potter, both produced precisely the same colour.

I wish some manufacturer would attempt to produce this ware by mixing the oxide of platinum with pure water only; for in that case I am persuaded the ware when finished would be as white as the platinum itself.

The potters of England have derived great advantage from the introduction of the printing press. The use of this valuable machine, which is comparatively of late date, has enabled these manufacturers to produce a greater variety of patterns, and of neater execution, than could possibly be acquired at a small expense by the pencil.

As this is a curious branch of the business, it will be proper to describe it a little more particularly. It consists in first printing the intended pattern with some metallic colour, chiefly the oxide of cobalt, on what is called *silver* paper, and then in transfer-

ring the colour from the paper to the surface of the porcelain. This style of colouring earthenware is a very successful imitation of the old blue porcelain of China, and of late years has been the means of extending the consumption of British pottery throughout Europe more than any other improvement in the manufactory; for the potters of China are totally unacquainted with the printing-press, and consequently all their designs are produced by the pencil alone.

This mode of imparting designs to the surface of earthenware or porcelain, and which is known in the trade by the appellation of BLUE PRINTING, is managed somewhat in the following manner:

One man constantly attends the press, which is very similar to our common copper-plate printing-press; and as soon as he has applied the colour—which is laid on the copper in the same manner as the copper-plate printers apply the ink—he lays it upon a hot iron, to thin the oil with which the colour is always mixed for this purpose. The oil which is used is a peculiar preparation of boiled linseed oil. When the colour upon the copper-plate is thus reduced to a proper consistence, a sheet of silver paper is laid over it, and the workman passes it, with the paper, through the press.

For blue printing, the oxide of cobalt is the only mineral which is employed. This is largely prepared in the Staffordshire potteries, and sells from 40*s*. to 60*s*. the pound, according to its intensity and goodness. Indeed, such improvements have

been made in the manufacture of this colour, that the Chinese potters are now supplied from England with all the cobalt they consume.

When the paper comes from the printing-press, it is, of course, found to be stamped with the intended pattern. It is then delivered, while wet with the colour, to a girl, who cuts off the superfluous paper with a pair of scissars, and passes it to another girl, who immediately applies it to a piece of biscuit ware, and then delivers it to a third, who fixes it more firmly by rubbing it very hard with a piece of flannel tightly rolled up in the form of a short cylinder.

The design of this hard rubbing is to force the colour into the pores of the ware. When the papers which have been thus applied have lain on for about an hour, the colour is generally found to be sufficiently fixed to admit of their being detached. This is effected by putting the articles into a tub of water, where the paper soon becomes soft and pulpy enough to allow of its being peeled off by gentle friction, leaving the full impression of the pattern upon the biscuit.

The papers having been removed, the ware is suffered to stand a sufficient time to become dry, and then it is put into an oven at a low heat, for the purpose of dissipating the oil, and preparing it for receiving the glaze.

It must be obvious that it is necessary to employ a glaze which is transparent, in order to give full effect to the brilliancy of the cobalt colour. A

little of this blue oxide is also generally mixed with the glaze, for the same purpose as laundresses employ smalt with their starch, viz. to increase the whiteness, by subduing any yellow tint that might otherwise impair its lustre.

Here I cannot avoid observing, that it would be an important acquisition if some suitable article, instead of oil, could be discovered for mixing with the colours which are employed in printing on earthenware, and which could be of such a nature as not to require to be burnt off previously to the application of the glaze. It appears to me to be worth while to institute a series of experiments for this particular object; because, if it could be attained, what immense quantities of printed goods, besides those which are ornamented by the pencil, might be completely finished with two firings, instead of three, which, on the present plan, such goods always require! Were it on no other account than the expense of this vehicle, it is desirable to find a substitute. Some of the first enamel-painters think it necessary to use even the best rectified oil of amber, and this, of late years, has been very costly.

Another idea occurs to me respecting printed ware, which, however fanciful it may now appear, will, I doubt not, some time or other be realized. What I refer to is, the possibility of printing two or three different colours at once, like the Lancashire calico-printers. This, I presume, would be a discovery of great importance to every manufacturer of

fine earthenware or porcelain. See Essay IV. vol. i. page 306, and also the engraved plate, No. XI. of the machine by which the calico-printers impart two or three distinct colours at once.

A red oxide of iron more brilliant than any hitherto employed would be also a valuable acquisition. That which is commonly used is procured from green vitriol by calcination; but I would suggest that a much finer colour might be prepared from *nitrate* of iron, and advise the potter to take several portions of it and precipitate the iron by the different alkalies, each in a state of causticity; and by these means he would readily discover which produced the best and the brightest colour. If four distinct precipitates were made, viz. one with lime, another with potash, a third with soda, and a fourth with ammonia, it is probable they would be found to be of very different value for the purpose of painting on china. The alkaline carbonates would probably give precipitates of inferior qualities; but by a subsequent calcination the carbonic acid would be separated, and something valuable might be produced.

In making this experiment, it will be necessary to prove all these different oxides on exactly the same kind of porcelain, or the result might be deceptive; for it is well known to practical men, that the oxide of iron will not produce the same fine red upon *common* china, as it will upon the hard porcelain which is glazed with felspar.

The residuum which is produced by those makers

of aqua-fortis who use sulphate of iron instead of sulphuric acid, might answer a good purpose, if thoroughly freed from the alkaline salt which it always contains.

It was my intention to have offered some remarks on the manufacture of crucibles, retorts and other chemical vessels, which are required to sustain a great heat; but having already extended this Essay much beyond its proposed limits, I must content myself with merely referring to those authors who have already treated on this subject. The most important of these is Pott, who wrote a work expressly upon it [95], as I have already mentioned [96].

I shall detain the reader, however, just to notice that the chief difficulty which the manufacturer finds in preparing such utensils as crucibles, &c. is, that if the portion of silica were employed which is necessary to give sufficient compactness, the ware would, from this very circumstance, be liable to become useless; because many of our chemical articles have the property of dissolving silica. An expedient has therefore been adopted of mixing a large portion of old pottery with the fresh clay, which gives it the desired weight, and yet is not liable to be dissolved by the alkalies like pure flint or sand.

I am moreover desirous of suggesting, whether it

[95] *Lithogeognosie Pyrotechnique, ou Examen Chymique des Pierres et des Terres.* 12mo, 2 vols. Paris, 1753.

[96] See p. 89 of this volume; Nicholson's *Chemical Dictionary*, 8vo, article Pottery; or *The French Chemical Dictionary*, under the same article.

might not be advisable to mix alumina and silica in certain proportions; and, having kneaded this mixture into balls, to burn them in an oven at the highest temperature the mixture can endure; and whether such a preparation would not be more suitable for grinding with fresh clay, than the old pots which have hitherto been used for this purpose. I imagine that vessels made in this way would stand heat and cold better, because the pores of the old stuff are often so close, that it cannot expand and contract by alternations of temperature as it ought to do. I mean, however, very soon to ascertain this by some direct and decisive experiments.

I am informed by a Sheffield manufacturer, that their cast-steel makers mix ground coke with the best Stourbridge clay, and that their crucibles for melting steel are made with this mixture. Pure earthenware is not fit for crucibles, or for any vessels that must expand or contract by change of temperature. This has been long known; Dryden notices it in one of his poems.

It is said that in France the very best crucibles which they have, are made with fine clay mixed up with old ground butter pots; and that these are composed of a peculiar kind of stone ware, which is manufactured in Normandy[97].

Where crucibles are required for melting metals, those made with plumbago are decidedly the best; but these are unsuitable for other purposes of the

[97] See the article Pottery in the second vol. of *The French Chemical Dictionary*.

laboratory, especially when salts and alkaline fluxes are employed in any process.

In a paper by Vandermonde, Monge, and Berthollet on the manufacture of steel, and which was published by order of the Committee of Public Safety in Paris in the second year of the republic, they say, "One of the greatest difficulties we find in this country (France) is to procure good crucibles [98]." The art of pottery in a manufacturing country like Great Britain is in all its parts truly important.

More than eighty years ago the celebrated Reaumur, in making some trials on glass, discovered, that if a vessel made of the common green bottle-glass be submitted to the heat of a potter's oven, imbedded in a mixture of sand and ground *sulphate of lime*, the glass of which it is composed will be changed in its appearance, and acquire some of the properties of the best Oriental china; become so hard as to strike fire with steel; be semi-transparent like porcelain, and will endure sudden changes of temperature without breaking. An account of these results was given in the Memoirs of the Royal Academy of Sciences for the year 1739.

Having mentioned this, I have only room to add, that the late Dr. Lewis, who conceived highly of this discovery, made many experiments to ascertain its nature and importance, the particulars of which, together with several most judicious remarks upon

[98] An abridgement of this memoir was afterwards published in the 19th vol. of the *Annales de Chimie*, page 13—46.

them, will be found in his celebrated work on the commerce of the arts [96].

The subject, however, appears to me to be highly deserving of still further investigation, especially as useful vessels of a difficult form may be made more easily of glass than of earthenware. If, therefore, a cheap and certain method of performing this species of cementation could be adopted, the operative chemist would have it in his power to procure a greater variety of chemical vessels, and those not only more durable but of more convenient forms than he can possibly obtain by any other means. I wish some potter would commence a manufactory of this kind. Such ware would be highly useful for many domestic purposes, to which none of the common pottery can be applied either with convenience or safety.

In returning to the subject of earthenware, it is proper I should state my opinion, that chemical vessels are often injured by the oxide of iron originally pertaining to the clay itself, as it acts like a flux, rendering this earth too fusible to admit of a proper union with the siliceous material of the ground pottery, which is employed in the manufacture of such articles. A question arises here, whether *oxide* of iron alone is prejudicial in this way, although its sulphuret, the pyrites, may. It may, perhaps, be worth while to decide this by experiment. Macquer says, that if a bit of pyrites be left in clay

[96] *Commercium Philosophico-Technicum*, p. 230—255.

which is to be exposed to a baking fire, it will form a cavity in the ware, and that this may be known by the circumstance of the cavity being stained black.

There is an old pamphlet of 9 pages in the London Institution, without title-page or date, on making porcelain, in which the writer speaks of a practice the Chinese have of purifying the earth they employ for the glaze, by means of aqua-fortis. On reading this, it occurred to me, that it might perhaps be worth trying, whether this expedient could be adopted with advantage in purifying such of our clays as are designed for the finest purposes.

For those articles in which the chemical nature of the body of the ware is of importance, it would perhaps be advisable always to wash the clay thoroughly; for, if pyrites be contained in it, the greater part of this would subside, on account of its superior specific gravity, while the argillaceous earth remained suspended by the water. For chemical jars, still-heads, &c., a *small* portion of iron would probably not be injurious. Vauquelin analysed the clay of which Hessian crucibles are made, and found it to consist of 8 parts oxide of iron, combined which 69 of silica, 22 alumina, and 1 carbon.

Clay which contains lime is equally improper for the manufacture of chemical vessels. If a clay be suspected to contain lime, or rather carbonate of lime, it may readily be discovered by an acid, which, if this earth be present, will occasion an

effervescence. When lime does not exceed five or six per cent., it appears to do no harm to the quality of the pottery; but when more abundant, it communicates too great a degree of fusibility: in like manner there are cases in which an admixture of the oxide of iron is useful and even necessary.

In the manufacture of what is called Delfware it has been customary to mix a portion of ferruginous clay with the other ingredients, because of its possessing a binding quality from which other species are exempt. The following are the usual proportions: Two parts of red clay, three of blue clay, and five of marle[100]. Most of the red clay is indebted to iron for the colour which it assumes; but when iron enters in any considerable quantity into the composition of the finer kinds of earthenware, it imparts either a red or a brown tinge to it; and besides this, it adds more fusibility to it than even lime.

Recollecting the circumstance just mentioned respecting delfware, it occurred to me, in reading one of the volumes of the *Archæologia*, that a certain iron-ore found in Scotland would probably be useful, when mixed in a small proportion, for some articles of pottery. I will give an abstract of the passage which caught my attention; and if any ingenious manufacturer should be able to avail himself of this hint, and convert it to profit, I shall be

[100] See Macquer's *Chemical Dictionary*, article Delfware.

rejoiced, and shall at any time be glad to be informed of the result, and the respective particulars which attended it.

In the Highlands of Scotland some very singular ancient walls are to be seen, which consist of "stones piled rudely upon one another, and firmly cemented together by a matter which has been vitrified by means of fire, and which forms a kind of artificial rock that resists the vicissitude of the weather, better than any artificial cement that has ever yet been discovered."

Mr. James Anderson, the person who has written upon these curious remains of antiquity, has found that through all the northern parts of Scotland, a peculiar kind of iron ore of a very vitrescible nature is in great abundance. Hence he supposes that "when the walls were reared and made as firm as could be by dry stones piled one upon another, the interstices between them were filled with this vitrescible iron ore, and the whole supported by a backing of loose stones piled behind it. When this wall was thus far completed, nothing more was necessary to give it the entire finishing, but to kindle a fire all round it, sufficiently intense to melt the vitrescible ore, and thus to cement the whole into one coherent mass[101]."

Dr. Lewis has related a remarkable instance of

[101] *Archæologia*, vol. v. p. 255, where also may be seen an account of a fortification of this kind in the county of Ross, with a print of it, accompanied by some ingenious observations worthy of attention.

the affinity of iron for silica. Having immersed some pieces of green glass in the red oxide of iron which remains after the acid has been expelled from green copperas, and baked it for several hours in the upper chamber of a wind furnace, the glass and oxide of iron were found to have run together into a black mass, of sufficient hardness to strike fire freely with steel. "It is remarkable," says he, "that a metallic substance so refractory in the fire, should be so greatly disposed to melt with green glass[102]."

Nothing can be of more importance to a potter than a thorough knowledge of the properties of the different kinds of clays. Dr. Campbell, in his Political Survey of Great Britain, states that we have not less than twenty-two distinct species[103]; and Macquer, who examined more than eight hundred specimens, says that in all that number he did not find one that was entirely free from metallic matter[104].

There is only one method, however, by which clays can be examined with any accuracy, and that is by the aid of chemistry. Such of my readers who are potters but not chemists, will therefore allow me to advise them to lose no time in acquiring the

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[102] *Commercium Philosophico-Technicum*, p. 245.

[103] Campbell's *Political Survey of Great Britain*, vol. ii. p. 16. Morton's *Natural History of Northamptonshire*, p. 71.

[104] Macquer's *Memoir upon Clays*, presented to the French Academy in 1762, and abridged in the *French Chemical Dictionary*, under the article Clay.

knowledge of analysing earths and minerals. Ample directions for the attainment of this art will be found in Kirwan's Elements of Mineralogy[105], or in Klaproth's Analytical Essays[106]; and I conceive it impossible that any manufacturer will ever regret the time which it may be necessary for him to devote to the acquisition of that elementary knowledge which would enable him to consult these distinguished writers with pleasure and advantage[107].

One or two instances of the mistakes which may occur in the examination of mineral substances, when they are not submitted to chemical analysis, will be sufficient to show the importance of this inquiry, and will, I hope, induce the junior practitioners at least, to adopt this advice, and enter upon that course of study which will be most likely to afford profit as well as entertainment.

The precious stones were formerly classed with siliceous fossils; and until Bergman and Klaproth[108] analysed several of them, they were generally supposed to be entirely composed of silica combined with a portion of colouring matter, to which they were solely indebted for their distinctive characters and appearances. An accurate analysis of several of these gems, particularly of the Sapphire, the

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[105] Printed in 2 vols. 8vo, London, 1794.

[106] Translated from the German, in 2 vols. 8vo, London, 1801.

[107] See more on this subject in vol. i. p. 21.

[108] See Bergman's Essay, entitled "A Dissertation on the Earth of Gems," in his Collection of Essays, vol. ii. page 76—121; and Klaproth's *Analytical Essays* before mentioned.

Topaz, the Hyacinth, and the Ruby, has, however, proved that either alumina, or zircone, and not silica, is in these instances the predominant ingredient. The Sapphire, according to Klaproth, consists of clay 98·50, oxide of iron 1, lime 0·50. The Topaz consists of clay 46, silica 39, lime 8, iron 6. The Hyacinth of zircone 70, silica 25, oxide of iron 0·50, loss 4·50.[109] The Ruby is composed of clay 40, silica 39, lime 9, and iron 10.[110]

The well-known article called Fuller's Earth, from its saponaceous texture had been supposed to consist almost entirely of clay or alumina; but, on an accurate analysis, it has been ascertained that the earth which enters into its composition in the largest proportion is silica. According to the analysis of Bergman, Fuller's Earth consists of silica 51·8, alumina 25, lime 3·3, magnesia 0·7, iron 0·7, water 15·5. Hence it may be accounted for, why it falls into a powder when put into water, and is incapable of forming a ductile paste. On the contrary, Emery, which has very much the appearance of sand or ground silica, is for the most part argillaceous earth or alumina, and the siliceous earth is in a very inconsiderable quantity[111].

The last instance which I shall adduce is one

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[109] Klaproth's *Analytical Essays*, vol. i. page 198.

[110] Bergman's *Essays*, vol. ii. p. 101.

[111] Emery from the Isle of Naxos is composed of alumina 80, silica 3, and iron 4, undissolved 3 parts. Tennant's *Analysis, Phil. Trans.* for 1802, p. 401.

that is intimately connected with our subject, and which shows decisively how necessary it is for a potter to be capable of undertaking a chemical analysis.

The porcelain earth of Baudiffero was pronounced by Macquer and Baumé to be a CLAY superior in quality to that which was then employed in the manufactory belonging to the French King at Sevres; and on their authority this was generally believed, till Mr. Giobert discovered that not a particle of clay could be found in it[112]. For, when this chemist attempted to convert it into alum, he found, to his great surprise, nothing but very pure crystals of Epsom salt, or sulphat of magnesia. After this, Giobert analysed this mineral with great care, and found it to consist of magnesia 68, carbonic acid 12, silica 15·6, sulphat of lime 1·6, and water 3.[113]

Since that period magnesian earth has been much employed in the composition of porcelain, it having been ascertained that a small portion of it prevents that great degree of contraction which always takes place in the fire, when clay and silica alone are made use of. The Cornish steatites or soap rock being a mineral containing magnesia, some of the English potters now employ it for this purpose.

I have understood, that in England the Steatites

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[112] See Murray's *System of Chemistry*, vol. ii. p. 253.

[113] Nicholson's *Journal*, vol. xii. p. 277, from the *Journal de Physique*, vol. lx.

was first used by the porcelain manufacturers at Worcester, and that they paid at the rate of 20*l.* per ton for it. In a well-known publication it has been stated that much of the land is in possession of the great Staffordshire houses, who have taken leases of it for the purpose of possessing themselves of this very valuable natural production. I learnt, however, in the year 1815, from most respectable authority, that *Steatites* had then never been employed by the Staffordshire potters.

The Steatites of Cornwall occurs at the Lizard Point, in a serpentine mountain which it cuts through in small perpendicular veins, called *rake-veins*. The finest sort is white, with blueish or reddish spots, resembling marble. The best analysis of this mineral gives silica 48, magnesia 20·50, alumina 14, oxide of iron 1, water 15·50, loss 1.[114]

It might perhaps be worth while for the glass-makers to try the effect of a small mixture of *Steatites* with the materials of which they make their large crucibles; because, if it prevent that great degree of shrinking to which they are now liable, it would be very advantageous.

I have been informed by an eminent maker of plate glass, that their crucibles, which are at first 32 inches deep, will not measure more than 29 inches when they have undergone the heat of the oven and become thoroughly baked; and that

[114] Klaproth's *Analytical Essays*, vol. i. p. 464.

this contraction has occasioned very great loss, especially in respect to the excise duty.

These glass-house pots are very large vessels, being made to measure nearly as much in diameter at the top, as in depth, consequently the shrinking on the whole is very great; and as the officer of excise gauges them before they are burnt, the manufacturer incurs a loss of duty upon as much glass as might be contained in the depth of 3 inches, and this loss recurs every time such crucible is charged; so that a manufacturer who pays 5000*l.* per annum in duty, must pay 500*l.* every year more than was contemplated by the legislature.

I am very glad however to have it in my power to inform my readers, that since this was written for the first edition of this work the hardship there complained of is entirely removed, the Government having made an alteration in the mode of collecting the duty on glass; for, instead of gauging the crucibles, the duty is now charged on the finished glass itself according to its actual weight.

Having ventured to offer these observations, I shall conclude with a few hints which to practical men may perhaps be useful.

There is a clay found in the territory of Sienna, in the province of Tuscany, called *fossil meal*, and by Kirwan Argillomurite, which is capable of making hard compact bricks that will float in water, either baked or unbaked. M. Fabroni, who examined some of these bricks in consequence of their having

been mentioned by Pliny[115], says that they may be of great use in the construction of reverberatory furnaces; for they are such bad conductors of heat, that although one of such bricks should be made completely red hot from one end to its middle, any person may take it up in his hand by the other end with impunity[116]. May it not then be worth while to inquire, whether a clay possessed of similar properties cannot be found in Great Britain?

Moreover, considering the improvements which have been made in the manufacture of pottery, might it not be easy to make bricks to imitate stone, and yet be as durable as the bricks now in use?

By means of the metallic oxides, would it not be possible at a cheap rate to stain bricks of any colour, and might not such bricks be made to imitate marble?

In the Essay on Barytes, vol. i. page 317, I have stated, that Mr. Wedgwood employed the sulphate of that earth in the manufacture of jasper; but if pure barytes itself or strontites could be procured without much expense, might not these also be used with advantage in some of the branches of pottery? A method of employing sulphate of barytes in pottery is indeed alluded to by Sage, in one of the volumes of the *Journal de Physique*. "The Chinese," says he, "know the remarkable property which gum adracanth has of giving a coherence to

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[115] See Pliny's *Natural History*, lib. xxxv. cap. 14.
[116] See *Philosophical Magazine*, vol. ii. p. 180.

minute stony substances, which are then unalterable by fire; and that if this gum be mixed with pounded sulphate of barytes, it may be formed into masses which neither alter their shape nor solidity from exposure to an intense fire [117]." I have not heard that any English potter has yet availed himself of this suggestion.

The sulphates of barytes and strontites may be had cheap and in abundance; and all that would be necessary is to roast them in a reverberatory furnace with some combustible matter, to convert them into sulphurets, and then the remaining sulphur, should it prove injurious, could be separated by a subsequent process [118]. In this way an ingenious manufacturer might probably gain unexpected profits and improvements from one or both of these earths.

In concluding this Essay, I trust I shall stand excused, if I endeavour to confirm an opinion already given, that a potter should never employ a new porcelain-clay without previous analysis; for there are few of these clays that can be employed with the certainty of a good result, unless some fusible material be used with them; and the quantity of this can only be known by a chemical examination of the clay in question. The necessity of analysis will appear from the comparison of the chemical

[117] See the *Retrospect of Philosophical Discoveries*, vol. i. p. 50.

[118] An account of a process by which this might be effected may be seen in Essay V. vol. i. p. 361.

nature of three of these native productions. The porcelain earth of Limoges, and which is often used without any admixture, is, according to Hassenfratz, composed of 62 parts silica, 19 alumina, 12 magnesia, and 7 sulphate of barytes; whereas the porcelain-clay of Cornwall is a compound of 20 per cent. of silica and 60 per cent. of alumina; while that found in the department of the Loire in France, of a beautifully white colour, consists entirely of carbonate of magnesia and silica.

The business of a potter affords so large a field for the exercise of taste and genius, and the art itself is so intimately connected with chemical knowledge and experience, that it would be superfluous to urge, by further arguments, the absolute necessity of cultivating the science of chemistry, in order to arrive at perfection in any branch of the manufacture.

The date of this elegant and useful invention is involved in great obscurity [2]. According to Pliny, the first vessels of glass were made in the city of Sidon [3]; but Loysel asserts that the glass works of the Phœnicians were in high renown more than three thousand years ago, and that they had merely depôts for the sale of their glass at Sidon and at Tyre [4]. The Egyptians also lay claim to having first made it, and say that they were instructed in the art by the great Hermes [5].

Flavius Vopiscus, who wrote the lives of Tacitus and others, in the reign of Dioclesian, observes, when speaking of Alexandria, that "it was very rich, abounding in corn; and that no one in the city was idle, for that one part of the poorer inhabitants were employed in the manufacture of paper, and the other in making *glass*." A late traveller who explored the interior of Egypt, has also assured us that the ancient inhabitants of that country made glass [6].

Pliny attributes the invention of glass entirely to chance, and relates, that it was first made in Syria by some mariners who were driven on shore on the banks of the river Belus; and who, having occasion

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[2] See Dr. Merrit's Preface to his Translation of Neri's *Art of Glass*, London, 12mo, 1662, and the Introduction to Blancourt's work above mentioned.

[3] Pliny, lib. xxxvi. cap. 26.

[4] *Essai sur l'Art de la Verrerie*, par le C. Loysel, 8vo, Paris, an viii. *Discours Préliminaire*, p. 1.

[5] Blancourt's *Art of Glass*, p. 9.

[6] Belzoni's *Researches in Egypt*, &c. quarto, page 173.

to make large fires on the sands, burnt the kali which abounded on that shore; and that the alkali of the plant uniting with a portion of the sand on which the fire stood, produced the first stream of melted glass that had ever been observed[7].

However this may be, there can be no doubt of glass having been in use during the time of Pliny, as it is often mentioned not only by him, but by many contemporary authors. The city of Herculaneum, which was destroyed about this period by an eruption of Vesuvius, contained glass. Besides utensils of glass, a large sized plate of the same compound was taken from one of the excavations. Josephus relates, that not far from Mount Carmel there is a round valley full of a clear sand fit for making glass; and that when the place has been emptied for this purpose, the wind from the mountains fills it again immediately[8]. But this historian could have known nothing of the nature of the manufacture of glass; for he asserts, that any metal when thrown upon this sand will be instantly converted into glass, and that, if glass be cast upon it, the glass itself will likewise be changed into sand[9].

Tacitus mentions the river Belus, but he speaks more rationally of the glass which was made in that neighbourhood than Josephus. He says, that this river flows into the sea of Judea, at the mouth whereof, the sand that is taken up, in consequence

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[7] Pliny, lib. v. cap. 19.
[8] *History of the Wars of the Jews*, book ii. chap. 9.
[9] *Ibid.* book ii. chap. 17.

of the great quantity of nitre contained in it, is by the heat of a furnace readily converted into glass; and that although the shore be small, the sand is inexhaustible[10].

The time when glass was discovered is unknown. Herodotus and Diodorus Siculus relate that the Ethiopians formerly inclosed their dead bodies in glass, and that the ancient Egyptians made glass of a dark colour in imitation of that manufactured in Ethiopia. But their magnificent cups evince a considerable knowledge in the art of making glass; and of which the Emperor Hadrian, then residing at Alexandria, thus writes to the consul Servius: "I have sent to you," says he, "some Alassian cups of various colours, given to me by the priest of the temple. They are dedicated to you, and particularly to my sister; and I desire that you will always produce them at your feasts on holidays[11]."

Several ancient writers relate, that, in the reign of Tiberius, an eminent Roman architect acquired great celebrity from the manner in which he had repaired a large portico in the city, which was giving way and seemed likely to fall; and that on account of his popularity, or some other such cause, the emperor banished him from Rome, forbidding him ever to return again. This individual, it is further stated, when in banishment, made experiments on glass, and, having discovered a mode of rendering

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[10] Blancourt's *Art of Glass*, p. 14.
[11] Bergman's *Physical Essays*, vol. iii. page 33.

it malleable, ventured again to Rome and found means of presenting one of his glasses to Tiberius, in the hope of not only being pardoned for returning without leave, but having his sentence altogether remitted; and that, on the contrary, the emperor was displeased at the invention, supposing that it would tend to lower the value of gold; and having learned from him that no one was acquainted with the method but himself, he ordered his head to be immediately struck off, that the dangerous secret might not transpire[12]. Pliny relates, that an artist who had acquired the art of making malleable glass, had his house destroyed by the enraged populace.

Blancourt asserts, that an ingenious Frenchman, in the reign of *Lewis the* JUST, also discovered the art of making malleable glass, and that he presented a fine image or bust, made with such glass, to the Cardinal Richlieu; who, foreseeing the injury which such an invention would do to the glass manufacture, ordered the artist into perpetual imprisonment[13].

We read of glass-houses being in use very early in the city of Tyre: and there is reason to believe that great part of the known world was at one time supplied with glass by the Tyrians, though it appears uncertain whether the great manufactories were in their city or in Phœnicia, as before mentioned. It has also been said, that glass-houses

[12] Dion Cassius, *Hist. Rom.*, Isidorus, and Petronius Arbiter.
[13] Blancourt's *Art of Glass*, p. 15.

were erected in Great Britain before it was visited by the Romans.

It is very uncertain when glass was first employed for the transmission of light and other optical purposes, or how long any of the nations of Europe have enjoyed the benefit of glass windows. I think I have read that the best buildings in Herculaneum had windows made with a sort of transparent talc[14].

One of our oldest English historians, Bede, tells us that in the seventh century it was not known how to make window glass in England; and that in the year 674, the Abbot Benedict sent for artists from abroad to glaze the church and monastery of Weremouth in the county of Durham. These men came probably from Venice; for the first glass that was manufactured in Europe was made there. Loysel thinks that the emigration of refugee artists of Phœnicia to Italy brought the glass trade first among them[15]. We learn also from Bede that the agents of the Abbot "brought several glass-makers with them when they returned, who not only performed the work required by Benedict, but instructed the English in the art of making window glass for themselves, also glass for lamps, drinking-vessels, and other uses[16]."

Notwithstanding the interest which so important

[14] See an Account of the Antiquities of Herculaneum translated from the Italian by Messrs. Martyn and Lettice, in quarto, with engravings.

[15] *Essai sur l'Art de la Verrerie, Discours Préliminaire*, p. 3.

[16] See Bede's *History of Weremouth*.

an application of glass was likely to occasion, it is probable that glazed windows were not common in these kingdoms until several centuries after the period above mentioned. Dr. Henry says positively, that although the art of making glass was introduced in the seventh century, it was afterwards so much neglected, that no private house had glass windows till after the conclusion of the tenth century[17]. Before that period the windows of houses and even of cathedral churches admitted the light through fine linen cloths or lattices of wood[18].

To prevent the surprise that may be occasioned to some persons, by the assertion that glass windows are comparatively but of late introduction in Europe, it may be remarked, that there are some countries on the face of the globe which have never yet enjoyed this luxury. This is the case at present at Rio-de-Janeiro in South America; for a friend of mine, who is largely concerned in the manufacture of glass, sent a considerable quantity of window glass cut into panes of different sizes, to that country, when the court of Portugal removed thither, in expectation of making a great advantage of it: but, when it arrived, the captain of the vessel had the mortification of learning that there were no window-frames in any of their houses, and consequently the glass would be useless. The glass was therefore sold for embellishing the images of the

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[17] Henry's *History of Great Britain*, 8vo, vol. iv. p. 118.
[18] William of Malmsbury *De Gestis Pontific.* p. 149.

saints, it being customary to decorate the walls of every house with such images and statues with glass before them, something in the way in which stuffed birds are preserved in this country.

It would seem that glass had not been long in common use for windows, or for the mere transmission of light, before the Monks became desirous of decorating it with ornamental paintings; for the art of painting on glass was brought into this country in the early part of the thirteenth century, during the reign of King John[19]; it having been practised in France some time before that period, and must then have arrived at a considerable degree of perfection, for it appears that the windows in the Abbey of St. Denys were painted in the twelfth century. The subjects of these paintings were the representation of the first Croisade, in ten different compartments, of which the engravings may be seen in Montfaucon[20].

So late as in the thirteenth and fourteenth centuries, the houses of the lower classes in England had not glass windows. Nor is it improbable that such windows were thought very magnificent even in churches; for Chaucer, who wrote towards the latter end of this period, in describing the dress of his parish clerk Absalom, says that the upper parts of his shoes were cut in imitation of the church window[21].

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[19] Walpole's *Anecdotes of Painting*, p. 5.

[20] Montfaucon, *Les Monuments de la Monarchie Française*, folio, Paris 1729, tome i. p. 384.

[21] Chaucer's *Works*, p. 26.

It is generally understood, that the houses in Italy were the first in Europe that were decorated with glass windows; that the custom was adopted in France soon afterwards; and that the French nation enjoyed that luxury a considerable time before England availed herself of the improvement.

Even now, in some of the least civilized parts of the Russian Empire, a kind of laminated gypsum called *lapis specularis*, found in abundance in that country, is used in windows as a substitute for glass.

Coloured glass, or glass stained during its manufacture, was known to the ancient Greeks and Romans; but it is only of late years that the English artists have acquired a knowledge of this process. Dugdale informs us, that when the citizens of London in the reign of Henry V. undertook to beautify St Paul's, one John Prudde, a glazier in Westminster, engaged to glaze the chapel "with glass from beyond the seas, of the finest colours, of blue, yellow, red, purpure, sanguine, and violet, and of all other colours that shall be best to embellish the matters, images and stories that shall be delivered to him, by patterns on paper, in rich colour, at his charges [22]."

From this testimony it appears that glass in considerable quantities was made on the continent of Europe earlier than in this country. In Bohemia glass is now made to a very great extent. There are even many towns that are dependent upon this

[22] Dugdale's *Antiquities of Warwickshire*, vol. i. p. 446.

manufactory, and the continent is chiefly supplied by these artists. Their practice is to fix upon a large wood, and cut down timber enough to allow them room to build. With this timber they erect a wooden house, together with sheds and warehouses; they then dig for clay to make the furnace: when this is ready they cut down timber for fuel, and from the ashes of the fuel and those of the brush-wood they prepare the alkali for the use of the manufactory. When the wood is cleared, and their fuel exhausted, these buildings are pulled down, and the workmen remove to another district.

The Government of France, in the early part of the fourteenth century, took great pains to improve the manufacture of glass, and ordained that none but gentlemen or the sons of the nobility should be allowed to exercise the trade, or even to work as artificers in the manufactories of this most highly esteemed commodity [23]. In consequence of this injunction, a company of persons of this description was incorporated, and obtained many important privileges and immunities from the state, particularly that of being allowed to work at this curious art without derogating from their nobility. It is indeed asserted, by the writer who is the best authority we have on this subject, that there never was an instance of any one being attainted to whom these privileges had been granted; for they conducted themselves so irreproachably, that their honours

[23] Blancourt's *Art of Glass*, p. 24.

were invariably transmitted inviolate to their posterity [24].

It was, probably, the success of the Venetians in this elegant art which induced the French authorities to interest themselves in promoting its establishment; for it appears that, in the thirteenth century, these people had established a manufactory of large glass mirrors at Murano, a populous village within one mile of Venice, where mirrors of such an uncommon size were made that they astonished all Europe [25]. Henry III. King of France, when visiting Venice, was so charmed with the work of the artificers at Murano, that he ennobled both them and their posterity [26].

In the year 1453, Anthony de Brossard, Lord of St. Martin and Prince of the blood royal, finding the business of glass-making to be so considerable, and knowing that it did not derogate from nobility, obtained a grant from the Prince to establish a glass-house in his own county, with prohibition of any other; and, in consequence of this, the elder sons of that family continued uninterruptedly to exercise the art till the latter end of the sixteenth century, when the proprietor was killed while commanding a troop at the siege of Chartres. Some time before this period, the Messieurs de Caqueray, gentlemen of ancient extraction, procured the right of glass-

[24] Blancourt's *Art of Glass*, p. 28.

[25] Busching's *Geography*, vol. iii. p. 83. Misson's *Voyage to Italy*, vol. i. part i. p. 300.

[26] Busching's *Geography*, vol. iii. p. 83. Misson's *Voyage to Italy*, vol. i. p. 301.

making by an alliance in marriage which one of their ancestors in the year 1468 contracted with a daughter of the Lord of St. Martin above mentioned, who gave up half of his right to the monopoly of glass for part of her marriage portion. This grant was afterwards confirmed in the Chamber of Accounts of the French Government [27].

On the death of Anthony de Brossard, the younger sons of his family undertook to carry on the art, and continued it for more than a century. Whether the trade continues still in the same line, I have not hitherto been able to ascertain.

An ancient family of the name of *Vaillant* also obtained the grant of a glass-house as a recompense for their valour and public services, together with a poignard d'or, on azure, for their arms [28]. Mr. Blancourt, who long resided in France, likewise notices that, at the time he wrote, they had many other great families among them, who were descended from gentlemen glass-makers that had declined following the art, and that some of these had been honoured with purple, and with the highest dignities and offices in the state.

Here it may be observed that the art of grinding and cutting glass for ornamental purposes was not practised till about the beginning of the 17th century. The inventor is said to have been Caspar Lehmann, who obtained in the year 1609, from the Emperor Rodolphus II., the title of "Glass-cutter

[27] Blancourt's *Art of Glass*, p. 30. [28] *Ibid.* p. 30.

to the Court[29]." The art of engraving on glass by fluoric acid was introduced by Henry Swenhard, an artist of Nuremberg, in the year 1670.[30]

The glass made in France had never been equal to that fabricated in Italy. But, while the great Colbert[31] was Minister of that country, a fortunate event enabled that eminent man to lay the foundation of this manufactory in the way which they had so long desired.

Certain French artists, established at Venice, found means to obtain at Murano an exact knowledge of the processes employed in the fabrication of plate glass, and they returned to France with the hope of enriching their native land with that splendid branch of art and of commerce. The Minister received them graciously; and, having empowered them to select such a situation as they might deem the best suited to their undertaking, they established themselves in the year 1665 at Tourlaville, near Cherbourg[32]. This Company afterwards obtained a patent for making plate glass, and an advance of 12,000 livres for four years was granted them by the French Government.

In the year 1688, Abram Thevart, an ingenious manufacturer, made a proposal to the Court for *casting* glass mirrors, and engaged that they should

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[29] Beckmann, vol. iii. p. 223.

[30] Nicholson's 4to *Journal*, vol. iv. p. 1.

[31] Something more respecting this extraordinary man will be found in vol. i. pp. 180 and 195.

[32] Loysel *Discours Préliminaire*, pp. 5 and 6.

be of a larger size than any ever before made[33]. This individual obtained likewise a patent to continue for thirty years; and the first plates which he cast[34] were made at Paris, and were of the extraordinary dimensions of 84 inches by 50 inches, a size which surprised all the artists of that day[35].

Notwithstanding this success, not more than three years elapsed before these proprietors found it expedient to remove their establishment to St. Gobin, in the department of the Aisne[36], and there they laid the foundation of a manufactory which is still in a flourishing condition, and is perhaps the most important one of the kind which is yet in existence.

In these stupendous works, plates for mirrors are now made of the vast size of 105 inches in height by 60 inches in breadth; and when they have been properly annealed they are conveyed to the Gobelins in Paris to be polished[37]. The double convex lens which I have described in the Essay on Temperature, vol. i. page 86, was made in the same manufactory. The instrument described above has been broken, and the Government have since caused to be fabricated at the same manufactory a massive plate of 2 metres diameter by 0·067 in thickness, weighing 500 kilogrammes; the largest piece of

[33] Mirrors of glass were attempted to be made in the ancient glass-houses of Sidon; but the artists could not succeed in the attempt. Pliny, lib. xxxvi. cap. 26.

[34] A very interesting and instructive paper on the antiquity of metallic mirrors may be read in Beckmann's *History of Inventions*, vol. iii. p. 164.

workmanship in glass that was ever executed, being in English measure $2\frac{1}{2}$ inches thick, 6 feet 6 inches in diameter, and weighing eleven hundred pounds avoirdupois.

It is now time, however, for us to look into the progress of this manufacture in England. The method of working in glass, as we have already seen, was introduced here so early as the seventh century; but I am inclined to think that for many ages our artificers made no improvement whatever in this curious art. Their business was probably confined to the manufacture of coarse window glass, and the most rude kind of culinary and drinking vessels.

Nevertheless, about the middle of the sixteenth century this country began to acquire eminence in the manufacture of glass, of which we have abundant evidence: thus in the year 1575 one of the London glass-houses was destroyed by fire; and Holinshed, speaking of it, says, "The same house which had consumed great quantities of wood in making *fine drinking-glasses* is now itself consumed[38]."

Manufactories of considerable consequence were afterwards established at Crutched Friars, and in the Strand, London; and these were much encou-

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[36] Savary *Dict. de Commerce,* tome iii. p. 87. Beckmann, vol. iii. p. 216.

[37] Loysel *Discours Prélim* ·e, p. 7.

[37] Busching's *Geography,* ii. p. 398.

[38] Holinshed's *Chronicle,* p. 1261.

raged by King James I. and Charles I., who both prohibited the importation of all foreign glass, excepting that of the most inferior kinds [39].

The former of these monarchs, as an expedient to raise money without the aid of Parliament, granted to Sir Robert Mansel an exclusive patent for making glass, and allowed it to be given out, that this monopoly was afforded him in consideration of, and as a reward for, his having substituted pit coal for wood in its manufacture; and that on the same ground he should be allowed the exclusive privilege of importing drinking-vessels and every other article of glass from Italy, which could be made there of a finer quality than had at that time been produced in England [40]. Common pit coal is however the fuel which is now employed throughout England for making all kinds of glass.

In the reign of King Charles the Second a Mr. Ravenscroft very materially improved the manufacture of flint glass. He is said to have made all kinds of glass drinking-vessels of a quality fully equal to any that were then manufactured abroad.

The Duke of Buckingham, who had brought workmen from Venice for the purpose, was likewise the means of establishing, about the year 1670, a considerable work at Lambeth for the manufacture of fine *plate* glass [41].

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[39] Rymer, tome xix. p. 663.

[40] Campbell's *Political Survey of Great Britain*, vol. ii. p. 28.

[41] Houghton's *Collections on Husbandry and Trade*, vol. ii. p. 43.

Thus by degrees was the manufacture of every kind of glass introduced into this country; and the trade made such rapid progress amongst us, that in the year 1696 there were no less than ninety glass-houses in the different parts of the kingdom. Of this number twenty-four were in London and Southwark, seventeen at Stourbridge, eleven at Newcastle-upon-Tyne, and nine at Bristol. The rest were dispersed in those other counties of England where coal is readily procured. Of these different manufactories forty-two were called Bottle-houses, or such as were chiefly employed in making the common black bottles; five were employed for crown glass; twenty-seven for flint, green, and other ordinary glass; two in making plate-glass for mirrors, &c.; and fourteen were exclusively appropriated to the manufactures of window glass[42].

We may naturally suppose that such a variety of establishments would give a permanence to any manufacture. This has really been the case; for, at this day, the art of glass-making has become one of the staple manufactures of our country.

It has already been shown that there are five different kinds of glass-houses in this kingdom; but before we attempt to describe any of the operations which are performed in them, it will be necessary to enumerate them afresh, as they are now rather differently distinguished from what they were a

[42] See further particulars in Houghton's *Collections*, vol. ii. p. 48.

hundred-and-twenty years ago, the time of which we have just been speaking.

The English glass-houses are now known by the names of the *Crown* or *Window* glass-house; the *Broad* glass-house; the *Bottle*-house; the *Flint*-house; and the *Plate*-glass-house. The glass trade of Great Britain has indeed become so considerable, that in general there are separate and distinct establishments for each of these species of glass. I know of no instance of the same proprietors being concerned in more than one or two of these different branches of glass-making.

It will be most convenient, however, and the nature of the whole manufacture will probably be better understood, if we begin the account of the different manipulations, by a description of the method which is adopted in making *flint* glass. The following is the process:

Lynn Sand	3 cwt.
Red Lead	2 —
Pearlash	1 —

To these are added a very small quantity of nitre, of manganese, and of white arsenic; and when these materials have been well mixed, the whole are combined with about one-fourth of their weight of old broken flint glass. These proportions are frequently a little varied, each manufacturer having his own ideas and peculiar practical knowledge on the respective properties of every ingredient.

It should however be mentioned, before we proceed, that some houses, instead of Lynn sand, use

a very white sand from Alum-bay in the Isle of Wight, and others procure it from Maidstone in Kent; and that the pearlash is always previously purified for this purpose. The following is the process:—First, it is dissolved in water, and suffered to remain some time undisturbed, to allow the impurities and contingent matters to subside; after this the clear solution is submitted to the action of heat, to expel the water and to reduce the alkali again to a dry state. One hundred weight of *first* [43] American pearlash is thus generally reduced to 70 or 80 pounds.

The materials being mixed, they are then, by a few shovels full at a time, cast into the crucible, previously brought to a white heat; and as these melt, more is thrown in until the pots or crucibles are all full, care being taken that the same temperature is continued till the ingredients are thoroughly united, and the whole formed into a perfectly transparent glass. The operation requires generally from 20 to 30 hours.

Flint glass is known to be perfect when the silica is all dissolved, and the paste is entirely free from sand specks and air bubbles. This however is never the case till the highest point of heat is attained, and the *metal* (a technical term of the workmen for glass in a state of fusion) has become sufficiently

[43] The potash and pearlash of America are sorted into three kinds by Government Officers chosen for the purpose; and they mark the casks *first*, *seconds*, or *thirds*, according to their respective qualities.

fluid to allow of the carbonic acid gas and other volatile matters to rise freely through the mass and escape. It is usual to ascertain the purity of the glass, by taking out a few ounces and blowing it into the shape of a long pear, with a small cavity within. This when cold is inspected, as a kind of proof or sample of the state of the glass in fusion.

When the glass is found to be completely formed, the workmen dip their instruments, which are long hollow tubes of iron, into the melted metal, and, turning them about several times, they collect, on the point of the instrument, as much of it as they require for any particular purpose which they may have in view. Then, by blowing with the mouth and rolling the hot metal upon a smooth horizontal iron plate, they form it into any shape that may be desired, such as glasses, decanters, phials, &c.

This part of the process is extremely interesting and even captivating to those who have never before seen the operation; for, without inspecting, no one can form an adequate idea of the facility with which the workmen form all sorts of vessels and instruments of this very curious and valuable material.

As it may be difficult for some persons who have not seen a glass-house to conceive how so much glass in the state of melting, as is necessary for making a large vessel, can be taken up on the end of an iron tube, it is proper to state, that every time the workman dips the instrument into the crucible of melted glass he exposes it a moment to the current of air, which chills the surface, and enables an-

other portion of metal to attach itself to the former; and this he repeats till he has collected a quantity sufficient for his purpose.

In the large houses, many workmen are constantly employed both day and night, because it is necessary that the work should go on without intermission, till all the metal in the furnace be exhausted. Each of these men has a boy to attend him; and these children are perpetually employed in carrying the articles, the moment they are made, one by one, to the *lier* or annealing furnace, where they are kept for many hours, in order that they may cool gradually.

The lier is a very long heated chamber, furnished with many shallow iron pans, called *lier-pans* or *fraiches*, for holding the goods; and these are moved further and further from the fire by means of a set of pulleys and a windlass, till they are brought to the other end of the gallery, where the temperature is so much reduced, that in general the articles are all sufficiently cool to be taken out with safety.

I observe in passing that the term *lier-pan* is perhaps derived from the French word *lier*, to bind or knit together; from an idea that the glass was not completely formed, or its particles properly united, until it had gone through the process which we now call annealing; and that the word *fraiches* is derived probably from the French *fraiche*, cool, or *refraichir*, to cool.

This process of annealing is absolutely necessary

for the production of perfect glass, whatever may be the kind, or whatever the form of the article which is made with it. Hence, it may be understood why glasses often break without any apparent cause; for, whenever this happens, it may be attributed to imperfect annealing, unless one side of a piece be more exposed than the other to heat or cold; for then it will inevitably crack, because glass is a worse conductor of heat than any manufactured commodity with which we are acquainted. This property of glass being a non-conductor of heat, is often exemplified in a curious manner in the glass-house. The following is a case that may be mentioned. When a crucible full of liquid glass breaks by accident, a large tub of water is brought to the mouth of the oven, and the fluid metal is laded with all possible expedition into it, to prevent its running into the furnace and being lost among the ashes. When this large mass of glass has been some little time in the water, its surface will become nearly cold, while the centre of it will be red hot, and continue so for several hours after the outside has been cold enough to be handled with safety.

Having thus given a very brief account of the method of making flint glass, it may be remarked, that either of the fixed alkalies, with a due proportion of flint or sand, will, without any other ingredient, make a pure and transparent glass. A century ago the best glass was always made from ground flints: hence it was that white glass

acquired the name of *flint* glass; but when it was discovered that good sand is nearly all siliceous earth, this was substituted for flints.

The other materials, viz. the lead, manganese, nitre, and arsenic, are therefore added with different intentions; and the proportions which are noted above are sometimes varied, for the sake of producing a glass of a quality different from that which is usually made.

Thus, the lead is employed with the design of giving a greater degree of fusibility to the silica, to add weight to the glass, to enable such of it as is designed for ornamental work to take a higher polish, and to render it less liable to break by sudden changes of temperature.

Besides the several uses of lead which I have enumerated, it has another effect upon all ornamental flint glass, which is of great importance; for it has the property of increasing the refractive power of the glass; and hence we are enabled to decompose the solar rays of light, by means of a glass prism, into what are called the prismatic colours. Lead is a simple combustible, and so are the diamond and hydrogen. It was Sir Isaac Newton who first suggested that the diamond, from its refractive power, was of a combustible nature, and that water also must have something in its composition that would burn, as it breaks the rays of light. Thus can we account for the superior beauty of the English flint glass. Plate-glass possesses no such brilliancy.

The employment of oxide of lead in the manu-

facture of glass is very ancient. In the collection of antiquities at St. Denis, an ancient mirror was shown which was said to have belonged to Virgil. It was an oval glass, 14 inches in length and 12 in breadth, and weighed 30 pounds. This was found on analysis to consist of artificial glass, mixed with a considerable portion of lead[44].

To explain the use of the other ingredients, it may be said that the manganese and the nitre are of service in destroying whatever carbonaceous substances may be in the mixture. The white oxide of arsenic is also used with the same intention. The employment however of this dangerous ingredient ought surely to be discontinued in the manufacture of drinking-vessels, because wherever the glass contains an overdose of alkali, it is liable to be attacked by acids: therefore acidulous wine standing long in a decanter might abstract some of the poisonous oxide, and produce infinite mischief. But this is, I fancy, seldom employed now, except where the manager suspects that the materials have been either not sufficiently purified, or that the calcination had not been properly conducted; each of these articles having the property of abstracting the carbon, and dissipating it in the form of carbonic acid gas, leaving the glass whiter and more transparent. There is however some nicety always required in the use of the oxide of arsenic; for, though it makes the glass whiter, it will give it an

[44] See *Hist. de l'Acad. des Sciences à Paris, année* 1787, p. 412; and Beckmann, vol. iii. p. 210.

opake or rather an opal appearance, if too much of it be employed. Some manufacturers of flint glass have discontinued it altogether, because they conceive that the lead renders the arsenic too volatile to be of much service.

The next species of glass to be described is that which is known in the trade by the name of *crown-glass*, being in fact the best sort of window glass which is made in this country.

The apparatus employed in the manufacture of CROWN-GLASS are, a reverberatory furnace for calcining the materials; a large furnace containing the pots or crucibles for melting these materials and forming them into glass[45]; and other furnaces for heating or annealing the crucibles, previously to their being employed. Besides these, there are others which contain no crucibles, but are merely employed for re-heating the metal time after time, to enable the workmen to keep it sufficiently ductile for being thrown into such forms as they require. The *bottoming-hole* and the *flashing-furnace*, as they are called, both come under this description. There are many other technical terms in this business: but they are all formed either from the Italian or the French language, glass having been long made in those countries, and it was from them that this art passed into the other states in Europe.

[45] One of these furnaces generally takes four or six pots; and these are so large, that some of them are capable of holding more than a ton weight of glass.

The materials which are employed in making the best crown glass are as follow:

Fine Lynn Sand	6 bushels.
Orkney Kelp	12 ———

These are the usual proportions; but some kelp will vitrify more, and some less sand than has been mentioned, because of the variation which there is in the quality of what is called best kelp.

Orkney kelp is preferred for window glass, because it makes it of a better colour than the Western Isle or the Scotch kelp. This is probably owing to the sand of the latter containing more iron. Mr. Bowles, the celebrated maker of crown-glass at Cock-hill, Ratcliffe-highway, London, always used Spanish barilla instead of kelp, and his glass was ever preferred to that of others. This gentleman had also an establishment at Vauxhall for making plate-glass: but the concern has been abandoned for more than twenty years, the proprietor having retired with an ample fortune.

It appears to me, that it would be a better practice to dry the materials thoroughly, and then to apportion them by *weight* instead of by measure as above mentioned. By repeated inquiries I have indeed learnt that one of the large manufacturers has adopted this method, and that the following are his general proportions:

Irish Kelp, dried and ground . . .	450 lbs.
Lynn Sand, dried	325 —
Slacked and Sifted Lime	25 —
	800 lbs.

These materials, when thoroughly mixed, are calcined for about two hours in a degree of temperature inferior to that of fusion; the fusion being in some measure prevented by constantly stirring the mass, which occasions a fresh surface to be perpetually presented to the action of the fire, and also favours the escape of the aqueous, gaseous, and other volatile matters which are required to be dissipated by the process. The heat is then increased till the whole becomes pasty; and it is preserved in this state for three or four hours more, constantly stirring the mass during the whole period. The materials, which are still in a soft and pasty state, are at length removed from the furnace, and, advantage being taken of the softened state of the mass, the whole is put very hastily into the form of square cakes, which are known to the workmen by the name of *frit*, the operation itself being called *fritting*. Some years ago I remember to have been very much at a loss to account for it, why it was necessary to make the glass first into frit, and why it might not be begun and finished by one process; but I now understand that whenever this previous operation is not performed, the alkali is apt to be driven off by the heat of the furnace, before it has time to combine sufficiently with the silica; whereas, in the operation of fritting, the temperature is powerful enough to effect this, and yet not equal to volatilize the uncombined alkali.

The manufacturers of glass, I trust, will not be displeased at my remarking on a circumstance which

is of more consequence than many persons are aware of. From my own experiments, I am warranted in saying that pure alkali evaporates at a lower temperature than is generally imagined. Hence great attention ought to be paid in preparing the *frit*, not to give it too great a heat, or to remove it from the calcining oven before it be thoroughly prepared; otherwise, the alkali will fly off in vapour instead of combining with the silica. This may be often seen arising as a vapour from the surface of the crucibles in a glass-house furnace. There is on this account an advantage in using *soda* in preference to potash, because soda combines more readily with the siliceous earth[46].

The manufacturers are desirous of keeping the frit as long as they can; and hence it is that the cakes are seldom employed immediately, but are generally piled up in a corner of the manufactory for future use, it being a prevailing idea, that the frit is better the older it is; and I have been informed that some of the opulent makers have a regular succession of it in store, and never use any that is not twelve months old.

To prepare for making crown-glass, this frit is put into crucibles in the melting furnace; and when the crucibles are filled, old glass is piled upon the frit, as high as it can be placed with safety. The

[46] An explanation of the process of fritting, and an account of the construction of the fritting ovens in France, may be seen in *Encyclopédie, ou Dict. Universel, Supplement*, tome vi. quarto, Yverdon, 1776, p. 618.

furnace is then made hot, and the heat is regularly increased till it acquire the maximum, at which state it is continued for 30 or 40 hours. During this time the materials become so thoroughly united as to form one perfectly homogeneous and transparent mass of fused metal, fit for the fabrication of sheets of best window glass.

To make this species of glass, the workman commences the operation as he would in the flint-house, already described. He dips the long iron pipe into the melted metal, and by repeated dippings gathers[47] as much of it round the end of the pipe as he knows by experience will be enough to form a table of glass. A *table* is the workman's phrase for a circular sheet of finished window-glass. These are generally 4 feet in diameter, and weigh 10, 10½, or 11 pounds each. Twelve of these is called a *side* or a crate of glass.

When the lump of metal is properly attached to the pipe, it is rolled frequently backwards and forwards upon a polished iron table, to change it from a globular to a cylindrical form. The workman then blows down the tube, to which the red-hot piece of glass is attached; and by this means, and a continuation of the rolling, it becomes expanded into a form similar to figure A, in Plate XIX., and which is called by the workmen a *Parisienne*. He then carries it to the mouth of the melting

[47] To *gather* is a technical term. The metal which is taken up by the iron is called a *gathering*.

furnace to heat it afresh, that it may be in a proper state for being further expanded by the breath, till it takes the form described by figure B; when it is immediately transferred to the furnace called the *bottoming-hole*, to be again heated; and this enables the workman to enlarge it, by the mere force of his breath, till it acquire the form described at figure C; after which, by heating it and blowing afresh, it assumes the shape of figure D. The artist having brought it into this latter form, the next object is to affix another working iron to the opposite side of the piece to enable him to detach with safety the first instrument. The intention of this contrivance will be rendered manifest as we proceed in our description of the process.

To effect this, the workman takes the glass which has been so far modelled, to a table covered with ashes, which are designed to prevent the adhesion of the glass to the table, and also to preserve the glass from too great a reduction of temperature; and while lying there, a supernumerary workman brings another working iron[48], with a small lump of hot metal at the end of it; and this he attaches to the piece of glass under operation, at the letter *Y*, exactly opposite to *Z*, the place where the first iron is still united.

Having by means of this small lump of fresh glass attached a new working iron, it becomes neces-

[48] This instrument differs from the former, in its not being a tube, but a rod of solid iron. It is called a *punt* or *pontil*.

sary to withdraw the former, as before mentioned, and this is effected by the usual expedient. The workman wets the end of a small iron utensil with a little cold water; with this he touches the glass at letter *Z*, where it produces a crack; then by a smart stroke he detaches the old instrument from it, which leaves a hole in the piece of glass of about two inches in diameter, and which has then the appearance shown by figure *E*.

A new working iron being now attached to the glass exactly at the opposite point to that where the former one adhered, the workman carries it by the punt [49] or new rod, to the flashing furnace, and turning it gently in his hand, holds it a few minutes at the small opening called the *nose hole*. This is a technical name by which these openings are known to the workmen in the North of England. Agricola and other old writers on glass called them *boccas*. This small opening into the large furnace is contrived merely for the purpose of heating that part of the glass to which the cold water had been applied. By this means it is put in a proper condition to be introduced into the larger opening in the same furnace, where it acquires heat by degrees till the operator perceives that the whole mass has again become sufficiently ductile. He then begins to turn it quicker and quicker, holding it the whole time

[49] These instruments are smaller and lighter than the blowing irons, and consequently more manageable in these latter parts of the process, when it is necessary to make them revolve in the hand with greater velocity.

at the mouth of the oven, till it becomes so much softened, that merely by the centrifugal force communicated by the rapid revolution of the iron instrument to which it is attached, and which requires great dexterity on the part of the workman, the whole mass opens itself by degrees, extending further and further till it assumes the form of *F G* and *H* in succession; and when it has attained the latter figure, it flies entirely open *in an instant*, as shown at *K*, and becomes one immense circular sheet of glass, 48 or 50 inches in diameter, and of one uniform thickness. It was formerly thought to be a great acquisition to be able, by this process, to make a perfect table of glass four feet in diameter; but I understand that Messrs. Attwood and Smith, formerly Hammond and Smith, of Gateshead in the county of Durham, are enabled to produce tables of five feet, which are the more valuable, as they yield larger squares than were ever made, except in plate glass; and the quality of it is of the best kind. The centre of the table of glass, where the punting iron was attached, is of course somewhat thicker, and is known to the workmen by the name of the *bull's eye*. Notwithstanding this, it is curious to observe how very uniform in thickness all the rest of the plate is.

This account of the varied manipulations is presented to my readers in considerable detail, together with drawings of the glass in every stage of its progress [50], because I believe the production of this pe-

[50] See the engraving, Plate XIX., prefixed to this Essay.

culiar species of glass to be one of the most curious and interesting processes which any of the manufactures of this or any other country can exhibit. The tenacity of heated glass is shown in a very striking manner by this operation; for though the plate be 50 inches in diameter, and not more than a line in thickness, it bears to be revolved in the hands of the workman with considerable celerity; and when it changes by its centrifugal power from figure *H* to figure *K*, it expands with a force sufficient to dash it, if it were cold, into ten thousand pieces. The workmen assured me that this circumstance never fails to arrest the attention of every visitor.

When the crown-glass is thus finished, the perfect plate is removed into the annealing arch, and there placed on its edge that it may become properly tempered by gradual cooling, as is practised in the manufacture of every other sort of glass. It is a very nice point to regulate the temperature of the annealing arch for a small excess of heat would render the plates so soft that they would bend out of the perpendicular and be much injured: on the contrary, if the furnace be not hot enough there is great danger of the plates flying in pieces, though if this should not happen the defect would inevitably be discovered by the glazier; since glass so imperfectly annealed is operated upon by the diamond with great difficulty, and it is almost impossible ever to cut it with exactness.

In the fabrication of crown-glass, nothing is of more importance than to keep the melting furnace

at its full heat during the whole time of the operation; for, whenever the men fall asleep, which they are apt sometimes to do, the heat of the oven gets checked, and it is almost impossible to bring it again to the former temperature.

This arises from the peculiar property which glass possesses, that of being a slow conductor of heat; and, unfortunately, the further the glass is advanced towards perfection the greater will be its liability to damage from this cause; and therefore the more solicitous should the manufacturer be, to watch this part of the process. This accident is of such frequent occurrence, that it alone has been the chief means of occasioning crown-glass to be divided into four classes, viz. firsts, seconds, thirds, and fourths; between the two extremes of which there is a difference of 50 per cent. in price. Indeed, if the excise duty be put out of consideration, the glass of the fourth quality nets the manufacturer less than half the price of the first. In one of the largest crown-houses which I have seen, where they make 1800 tables, or 150 sides per week throughout the year, they consider one-half to two-thirds of this quantity to consist of seconds and thirds. When the firsts were sold at 6*l.* 10*s.* per side, the thirds brought only 4*l.* 18*s.*, the duty being paid by the maker.

The next species to be described is BROAD-GLASS, or inferior window glass. This is quite a distinct manufacture from that of crown-glass, and the pro-

case of fabricating it is also totally dissimilar. The materials which are employed, and the method of conducting the operation, are as follow:

Six bushels of soap-boilers' waste [31], three bushels of kelp, and four bushels of sand are mixed together and cast into a calcining furnace. But there is no absolute rule for the proportions, because the two first of these materials are as variable in their qualities as can well be conceived, and therefore the operator is always guided by his own judgement in apportioning the respective quantities, and nothing but practice can direct him.

I have not found that the proprietors of those houses where broad-glass is made lay any stress on the fineness of the sand; but this is certainly an important circumstance. Loysel has stated, as the result of his own experience, that if coarse sand be used, 2lbs. of pure alkali must be put to every 4lbs. of sand, or it will not melt; whereas if the sand were very fine, 1lb. of pure soda would be sufficient. Hence it follows, that there remains in the finished glass, as a constituent part of its substance, only one half of the alkali at first employed. The other half is dissipated during the process, and entirely lost [32].

The process of calcining the materials requires from twenty to thirty hours, and is designed to burn off all the inflammable and heterogeneous matters

[31] This is the refuse article which is spoken of at page 11 of this volume.

[32] Loysel, page 180.

which would spoil the colour of the glass, as well as endanger its boiling over when it came into the melting furnace. It is observable that the materials are not suffered to melt while in the calcining furnace, but are kept at a great heat and stirred very frequently with an iron rake, which facilitates the separation of the gas, and completes the combustion of all such contingent matters as are capable of this change.

When the mass has been thus properly calcined, it is removed with iron shovels while red hot, and carried to the melting furnace, where the pots are entirely filled with it; and in the course of twelve or fifteen hours of exposure to a due degree of heat, the whole will become perfect glass. To form this into sheets, the following method is pursued:

The glass is withdrawn from the pots by iron tubes in the way already described for the flint and crown-glass [53], and it is blown into globes, or rather into hollow cones, of about a foot diameter. It must be recollected that all glass, the large plate-glass excepted, whatever be its form, whether that of an electrical tube, a goblet, a decanter, or a sheet of window glass, is all fashioned from a hollow sphere produced by the action of the breath. That is, a piece of fluid metal is first blown into a hollow globe, and then it is moulded by the workman into the desired shape. When these globes are formed, they are carried again to the mouth of the oven, and

[53] See pages 180 and 195.

while there, one side is touched with a cold iron dipped in water. This produces a crack, which runs along it longitudinally in nearly a direct line. When this crack is produced, the cone is opened upon a smooth iron plate fixed at the mouth of the furnace, and it then forms a sheet of thin transparent window glass in a shape somewhat like that of a fan. In a few minutes this becomes hard enough to admit of being removed to the annealing apartment, that its temperature may gradually diminish. This species, which is, probably, the first that was ever manufactured for the use of windows, is called *broad* or *spread* window-glass, to distinguish it from what is termed the crown-glass.

Another kind not yet described, is a green glass, known to the trade by the name of BOTTLE-GLASS, and the works at which it is manufactured are called *bottle-houses*.

To make this species they take three bushels of soap-makers' waste ashes, and one bushel of coarse river sand. Sometimes a portion of kelp is also added, but this is not used in all manufactories. These materials are calcined either in a distinct furnace, or in arches attached to the furnace of fusion, where they are kept at a red heat for twenty or thirty hours[54]. From thence the mixture is removed, still of a red heat, to the melting furnace, where by

[54] Neri prescribes only 10 or 12 hours, see Merret's Translation, page 272; but I have reason to think that the modern is the better practice.

means of iron shovels the pots or crucibles are filled with it, and an intense heat is again applied. By continuing the materials in this high temperature for twelve, fifteen, or eighteen hours longer, they become perfectly fused and converted into a true glass, fit for making wine bottles, garden bell glasses, chemical retorts, aquafortis carboys, and any other large vessels for chemical laboratories or other purposes.

These articles are all fashioned by a method similar to that which has been described under the article flint glass [55], excepting half-pint, pint, and quart bottles, which are blown in a *mould* either of iron or brass. These goods are likewise removed, while yet very hot, to the annealing furnace, for the purpose already mentioned in describing the other species of glass.

The bottle metal is peculiarly fit for making chemical carboys, as it bears the action of all the mineral acids without sustaining any injury; whereas flint glass, which is usually made with a large portion of lead, is very unfit for any chemical purpose that requires much heat. Bottle-glass, which is always made without lead, will bear a greater heat without melting, and therefore is much better adapted to many of our operations.

A few observations now present themselves as necessary to be offered on the process of bottle-glass, before we proceed with the remainder of our subject.

The soap-makers' residuum contains a very great

[55] See the Text at pages 180—188.

proportion of *carbonate* of lime, which is better for this purpose than lime itself, inasmuch as it helps to decompose the sulphates of soda and potash, which are always contained more or less in soap waste, as well as in kelp and the other alkalies of commerce.

There must be a great loss in using the sand in its coarse state, for the reasons already assigned. In some glass-houses on the Continent it is usual to heat the sand red hot, and then throw it suddenly into cold water, in the same way as the potters treat their flint to break it into smaller grains. Why might not our manufacturers, where coal is cheap, adopt this practice? If pains were also taken to wash the Woolwich sand repeatedly in several waters, the colour of the glass made with it, would, I conceive, be much improved.

Government will not allow the makers of this species of glass to use any but the commonest river-sand, lest the glass should be too good, and the revenue be defrauded by its being applied to purposes for which the best glass is generally used, and which pays a higher duty. The greatest proportion of the sand which is used in bottle glass is obtained from the river Thames at Woolwich.

I have reason to believe that at most of our English bottle-houses, the calcining is conducted in arches communicating with the furnace in which the metal is founded. In those houses which I have seen there is an arch at each corner of the main furnace, and in these arches the materials remain

not only the whole time of founding the former parcel of glass, but also during the time of its being worked up into bottles, &c. which is generally 10 or 12 hours more. Care is taken at the latter part of this period to bring the calcined mixture in the arches to such a temperature, that it may be moved immediately from thence into the hot crucibles without danger of breaking them.

In the neighbourhood of Newcastle-upon-Tyne, bottle-glass is made very profitably from a mixture of lime and sea sand, the mass having been first repeatedly wet with salt-water. Where glass is thus attempted to be made without any alkali, except what is contained in the muriate of soda, lime is absolutely necessary; for this earth when in conjunction with silica seems in a high temperature to have the power of decomposing common salt. I cannot, however, speak decisively, because I have doubts on this subject. I wish some manufacturer, who has a favourable opportunity for making the experiment, would have the goodness to satisfy me upon this point. The alkaline *sulphates* I know are decomposed by a mixture of charcoal and *carbonate* of lime in a high temperature.

The preference which is given to the Orkney kelp, may, I suspect, be accounted for on similar principles. This species of kelp contains usually 2 cwt. of lime in every ton, produced from the incineration of the sea shells which are entangled in the weed, and this lime is useful in decomposing

the muriate of soda which is always contained more or less in every kind of kelp.

The only species of glass which now remains to be described is that of PLATE-GLASS. Of this there are two kinds, viz. the one made by blowing and opening, somewhat similar to the mode of making the spread window-glass already described; the other is produced by casting upon a table in a way something like that of forming sheet lead. Plate glass of a considerable size may be made by the first of these methods, but the largest mirrors can only be made by casting. Much of the small plate is consumed in the navy and by merchant vessels for glazing the cabin-windows, as no other kind of glass can be depended upon in rough weather.

There are, I believe, only two establishments throughout the united kingdom for the fabrication of plate-glass. The first and most considerable is at Ravenhead in Lancashire, where the largest plates in the world, and inferior to no foreign plates, are made, and these are produced by casting. The other is at East Smithfield, London, where the work is performed by blowing.

I express myself in this decided manner respecting the work at Ravenhead, in order to counteract the declaration of an eminent French manufacturer, who has thought proper to publish the following statement:—"All that the English glass-houses do, may," says he, "be executed, and in fact is executed, with more facility in ours. But they

are obliged to give up to us the fabrication of *plate-glass*, and of our fine light glass, made with pure saline fluxes[57]."—Those who have seen the superb collection of English plate-glass which is constantly on show at Blackfriars, will be not a little surprised at the unqualified nature of this assertion.

In the formation of good plate-glass, the first consideration is that of preparing the soda, this being the species of alkali which is usually employed, and, I believe, from sound reasoning, always preferred for plate-glass. To procure the soda for this purpose, muriate of soda (common salt) is decomposed by means of sub-carbonate of potash, both salts being in a state of solution and assisted by heat. After this, a portion of the muriate of potash is separated from the solution by priority of crystallization, when the remaining alkaline solution is boiled to dryness and reserved for use. Formerly kelp-ashes and even weed-ashes were employed, without any previous lixiviation, in making plate-glass. Consequently the glass was then coloured, and not so brilliant as the modern. In the great work at St. Gobain they used nothing but wood-ashes for many years.

After the alkaline salt has been prepared as above, it is in some measure necessary to analyse it, with a view to ascertain how much real alkali is contained in it, and hence how much sand such a salt will require. When this is known, the calculation is made with-

[57] Loysel, page 86.

out difficulty; for it has been found that one pound of pure soda is sufficient for four pounds of sand; and if this quantity of sand be employed, a hard compact glass will be produced that cannot be injured by the action of water, or even any of the common mineral acids. But where so large a proportion of silica is used, it is necessary to employ a heat not less than 18,000° of Fahrenheit, it having been determined that silica is dissolved by alkali in proportion to the height of the temperature at which the founding is conducted.

On the principle that one pound of soda, free from every impurity, will be sufficient for four pounds of sand, then, if the prepared alkali should contain 40 per cent. of real soda, which is about the usual quantity, the remainder being muriate of potash, carbonic acid, and water, the operator would take 160 lbs. of sand to every 100 lbs. of such salt. Upon these data, therefore, the following proportions of the materials will produce a glass suitable for the best plates:—

	lbs.
Lynn sand, previously well washed and dried . .	720
Alkaline salt prepared as above	450
Quick-lime slacked and sifted	80
Nitre	25
Cullet, or broken plate-glass	425
	1700

These quantities of the different materials are required to produce one pot of metal; and if the

process be well conducted, this will make 1200 lbs. of good plate-glass. This will, however, depend in some measure on the size of the establishment. Loysel has given a detailed account of the principal dimensions of the French houses for making plate-glass, and has introduced it by saying that those proportions have already served as a model in several glass-houses, and that experience has justified his opinion of their goodness [58].

Dr. Merret calculates that 1 cwt. of sand yields 150 pounds of glass [59]. This produce is, however, greater than can be realized, if the founding be properly conducted.

The whitest sand which I ever saw is found in the Isle of Wight, at Alum Bay, very near the Needles. I suspect this would make finer glass than the Lynn sand above mentioned. When I was in the county of Hants, I inquired the price of this very peculiar sand, and found that it is sold at 12*s.* per ton, delivered at Yarmouth in the Isle of Wight, on board the vessels which go thither for it. The importance of pure sand for the manufacture of glass has been acknowledged for many ages. For more than a thousand years before the commencement of the Christian era, the sand found on the shore of Belus, a river in Phœnicia, was reckoned the only kind fit for making glass; and even after the time of Christ it was collected, and taken away

[58] See his work on *Glass*, page 86.
[59] *Observations on Neri*, page 211.

by vessels that came annually from foreign countries, as Strabo, Josephus, Tacitus and others affirm.

Lime is employed on account of the property which it gives to glass, of being a better conductor of heat, and consequently rendering it less liable to break by sudden change of temperature; and because such glass cuts more readily by a diamond than that which is purely siliceous. It is important, however, to use quick-lime, and not the carbonate, as the latter occasions so much swelling of the materials as to endanger their flowing over the sides of the crucibles.

The quality of the lime is of considerable importance. Lime for this purpose has sometimes been made with stone brought as ballast from Gibraltar, and it answered better than the chalk lime in the neighbourhood of London. I am informed, however, that the best lime for the glass business is that of St. Vincent's Rock, near Bristol.

Nitre is very effectual towards depriving the materials of every species of carbonaceous matter; and hence it improves the colour of the glass, its oxygen uniting with the carbon, and forming with it carbonic acid gas, which goes off in vapour. Nitre has also the property of rendering glass more transparent.

Before we proceed further on our subject I wish to inform my readers, that, for the production of the soda, the glass manufacturer is allowed com-

mon salt free of duty; which is a circumstance of considerable importance, especially as I have reason to believe that there are some glass-makers in the kingdom who are not aware of the full value of their privilege in this respect. Every manufacturer of glass is entitled to this allowance, whatever the species of glass may be which he is in the practice of manufacturing; I have therefore thought it would be rendering an acceptable service to some individuals to inform them how they may readily decompose common salt, and also how dispose of the residuum to advantage which arises from the process.

It will be necessary in the first place to make an entry of a room for making mineral alkali, or *flux for glass*, as it is termed in the act of parliament[60]; and when due notice has been given to the officer of excise who surveys in the district, the manufacturer may commence the business. The following is the process which has usually been adopted by those makers of glass who prepare their own alkali:—

Any quantity of common salt is dissolved in a boiler of hot water, and nearly double its weight of American or Russian pearl-ash is added to it. This mixture will produce a double decomposition, and two new salts will be produced, viz. muriate of potash and carbonate of soda. I know indeed of one manufactory where only 5 cwt. of pearl-ash is

[60] See the 38th of Geo. III. cap. 89, § 116.

employed to decompose 3 cwt. of muriate of soda, and I doubt not that when the pearl-ash is good this quantity will be sufficient, because we know that 100 lbs. of pure subcarbonate of potash are equivalent to 85lbs. of muriate of soda.

When the liquor in which these salts have been dissolved is concentrated by evaporation to a certain point, which may be easily known by a little experience, the muriate of potash will crystallize; and then the remaining alkaline liquor may be further evaporated till the carbonate of soda be recovered in a dry state. The mineral alkali thus produced may be used instead of purified pearl-ash, in the manufacture of the finest kinds of glass, and the muriate of potash may be sold for the purpose of making alum, for which it is a very suitable salt. It is important not to use iron vessels for this purpose where it can be avoided; for, if the alkali be designed for the superior kinds of glass, there will be a chance of its gaining colour from metallic impregnation.

An especial act of parliament was passed so lately as the year 1813 to permit glass-makers to dispose of the muriate of potash obtained in this way, on paying an impost of 20*s*. per ton[61].

I conceive it might be worth while for a scientific glass-maker to institute a series of experiments to determine whether muriate of potash or muriate of soda, in their entire form, might not be em-

[61] See pages 3 and 9 of the Act already quoted.

ployed to advantage in making some species of glass.

It appears to me that every glass-maker should prepare his own alkali, because he has the exclusive advantage of a drawback of the whole of the duty on the salt employed, and he will then have a more suitable alkali for his business; and considering that soda will saturate more silica than potash, the saving will be very considerable on the amount of the alkali consumed.

Provided soda could be procured at the same price as pearl-ash, it would be preferable on another ground, viz. that the same degree of temperature will always produce a more fluid metal; consequently this alkali ought exclusively to be used for making *cast* plate-glass.

The maker of mineral alkali for glass will have a duty of 20*s*. per ton to pay on the whole of the soda produced; but as he has the liberty of finishing his process before the duty becomes chargeable, he may contrive to pay only upon the *pure* alkali, which will amount to a very trifling impost[68].

In resuming the relation of the process of making plate-glass, I feel much difficulty in marking out, without being tedious, the exact line of description, so as to render the account in any degree interesting; for I am aware that, were I to enter into all

[68] See 38th of Geo. III. cap. 89, § 2.

the minutiæ of this business, the mere detail would of itself occupy a volume. The following circumstances, however, which all refer to the method of making plate-glass by the process of *blowing*, seem to deserve our attention.

In order to acquire an idea of the expense of erecting and keeping in repair a furnace for making plate-glass, the reader may consult the Translator's Notes to Beckmann's History of Inventions[61]. He says a furnace for preparing the glass for *casting* large glass plates, before it is fit to be set at work, costs 3,500 pounds. A furnace for a plate-glass-work, where the plates are made by blowing, will of course cost considerably less.

When the materials employed have been sufficiently comminuted and properly united by turning them frequently backwards and forwards upon a floor, the crucibles within the furnace are carefully filled with the mixture, the conciator or founder taking care to have the furnace previously made as hot as possible. Ten hours generally elapse before these materials are totally melted; for during this time the pots are much cooled, and the fusion checked by the repeated addition of fresh portions of the materials.

"The solvent power of a saline flux upon silica in a state of fusion, is proportioned to the extent of surface presented to its action and the existing force of aggregation. Thus, if a mixture of one

[61] Vol. iii. p. 206. ed. 1814.

part of fixed alkali with two of quartz *reduced to powder*, be put into a crucible exposed for a due time to the heat of a glass-furnace, the vitrification will be complete; but if the quartz be mixed *in lumps* instead of powder, vitrification will only take place on the surface and in strata; a portion of the alkali will be dissipated by the fire, a small quantity of glass will be produced, and there will remain a great portion of the quartz unmelted[64]."

The articles being all melted, the next object is to refine the metal thoroughly; and this is effected by continuing the heat at its maximum for several hours longer, till all the neutral salts, the aqueous, carbonaceous, and gaseous matters have disappeared, and the glass is become free from specks or globules of air, and destitute of colour. To describe this state the workmen employ a technical phrase, and say that the metal is become *plain*; and when it is announced that the glass is *quite plain*, they mean that it is entirely finished and quite perfect; whereas in the crown-glass-houses the metal at this stage of the preparation is said to be *fine*, meaning that it is refined or purified by the dissipation of the air bubbles, &c.

When the contents of all the crucibles are brought exactly to this state, a workman goes into the ash-pit, or cave, as it is called, and carefully closes up the openings between the bars of the grate with a composition consisting of clay and cut straw, to

[64] Loysel *sur l'Art de la Verrerie*, page 18.

prevent the introduction of any air into the furnace through the fire-place, which would endanger the rupture of the pots, and produce too rapid a cooling of the furnace. Some excellent directions for the construction of furnaces, so as to prevent the walls from cracking, are given by Loysel in his work on glass[65].

It is necessary in this stage to secure every opening into the furnace; because when the metal has become *plain*, it is not in a fit state for being worked into plates of glass by the process of blowing; for at this high temperature it would be too fluid to adhere to the irons when dipped into it, or to preserve the shape which it is necessary to give it before it can be converted into a plane surface fit for being made into mirrors. It must therefore be allowed to cool gradually for nine or ten hours after every orifice has been closed, as before mentioned.

The temperature of the prepared metal being thus reduced to the working state, it is modelled in a manner very similar to that of flint-glass, already described[66]. A workman dips an iron pipe into the crucible, and having taken out a little of the fused glass upon the point of the iron, waits a moment till that has adhered: he then dips it in again and rolls another portion round the former: this he repeats, till he finds he has taken up enough

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[65] Loysel, page 51.

[66] See the former part of this Essay, pages 186, 187.

for his purpose. Then, by blowing down the iron tube, he expands the mass of glass a little, and produces a hollowness within it: this he enlarges by repeated blowings till it forms a globe of 12 or 14 inches in diameter, or more, according to the size of the intended glass-plate.

At St. Gobin it is usual to sprinkle with water the first portion of metal that is taken up on the point of the iron, in order to make it adhere better to the instrument, and thus be able to support a greater weight of glass in the subsequent immersions in the crucible.

The next object, in this stage of the process, is to convert the globe into a cylinder. This the workman effects by giving the rod to which the soft glass is attached, the motion of a pendulum. It is then heated afresh at the mouth of the furnace, and a hole is punched in the centre of that end of the cylinder which is furthest off the working rod. This is done with an iron chisel and mallet; and as the glass is previously softened by heat, there is no danger in the operation. The orifice which has been thus made is afterwards widened by an instrument kept for the purpose; and then, a pair of shears being introduced, a slit is made in the cylinder of glass extending to one half of its length.

It being necessary, however, that the cylindrical form should for the present be preserved, another workman applies a temporary rib of glass, which has been previously attached to a working rod, across that end of the cylinder which has thus been cut

open. This instrument, which is called *a pontil*, is not hollow like the blowing irons, but is merely a metallic rod about 6 feet long. In France the pontil for making plate-glass has a bar of iron across the end of it, forming a T, and the rib of glass designed to be attached to the cylinder is put within a slit in the edge of the cross bar, which is designed for that purpose.

When this is done, the other rod is detached, in order to allow of that end of the cylinder being also heated, opened, and slit up with shears as before practised. The whole of the cylinder being thus divided, the pontil is detached from it, and the glass is carried to the spreading oven, where it is laid upon an elevated floor covered with a thick stratum of sand, to prevent the adhesion of the glass in its softened state. In a few minutes it is pushed on to an adjoining apartment, where it is quickly placed in a vertical position to anneal. So much care is necessary in this business, and the work is so laborious, that one man seldom makes more than 10 or 12 plates in the course of 24 hours.

The annealing kiln or oven having been thus filled with the plates of glass, each standing on its edge, the doors and the chimney are closed and carefully luted with clay, to prevent the possibility of any cold air entering the chamber for the space of twelve or fourteen days; after which the lutings are gradually loosened, and the glass is removed into an open part of the glass-house to attain by degrees the temperature of the surrounding atmo-

sphere. When an hour or two has elapsed, these plates may be carried with safety to the cutting-room, and there they are trimmed round the edges with a diamond, and by other means, to prepare them for the operation of grinding. According to Pliny, the ancients used diamond powder for polishing the precious stones: but Beckmann says that the first mention of a diamond being used for writing on *glass* occurs in the sixteenth century. Francis I. of France wrote the following lines with his diamond ring upon a pane of glass, to let the duchess of Estampes know that he was jealous:

"Souvent femme varie,
Mal habil qui s'y fie."

The ancients must however have been acquainted with our method of grinding glass, for Pliny speaks of its being turned by the wheel and engraved on like silver[67].

To describe all the preparations and conveniences of the grinding apartment in an English plate-glass-house, together with the varied processes of rubbing down the plates to one uniform thickness, would extend this Essay beyond its prescribed bounds: but an outline of this part of the business must be given. And with regard to the uniformity of thickness, this is necessary not only for mirrors but for the navy, where the superintendants are very circumspect in having the glass all of the defined thickness. There is an officer at

[67] Lib. xxxvi. § 26.

each of His Majesty's dock-yards who is provided with a gauge to measure it, and whose duty it is to reject all those squares that do not correspond to the fixed rule. The size which is most commonly used is of the thickness of 3-16ths of an inch.

In the grinding apartment the glass plates designed for mirrors or other purposes, to which plate-glass is applied, are imbedded in plaster of Paris upon a suitable table or bench, care being first taken to fix them perfectly horizontal. When the table is thus filled, other plates are attached by plaster of Paris to another plane surface; and these being suspended over the lower table, are made to traverse by a regular motion upon the surface of the former. This is effected by means of a power obtained from a steam-engine; and when the upper set of plates are thus set in motion, the attendant casts a certain quantity of sand and occasionally a little water between the two surfaces: it may therefore easily be conceived that, by continuing this motion with repeated additions of sand and water, both surfaces will be abraded and ground down to any thickness that the operator may require. When these plates are properly ground by a succession of sands of different degrees of fineness, which are all distinguished by well-known numbers in the same way as the sportsman distinguishes his leaden shot, the plates are detached from the plaster of Paris; and having been turned so as to present the other side, they are reset in the plaster, and the same operations are repeated.

There is a process which precedes this, called *ruffing*, and other manipulations, before this business of grinding is finished. But these are so varied and multiplied that it is impossible to describe them without more prolixity than I am willing to impose upon my readers; and even then the manufactory must be visited before I could be thoroughly understood[68].

It may, nevertheless, be noticed, that the process of grinding reduces every hundred weight of rough plates, independently of breakage, to less than half a hundred, and that the glass which is ground off is deemed unfit for any other purpose of glass-making[69] except that of black bottles, because it is mixed with so large a portion of common river sand. It has therefore generally been either sold at a very low rate for scouring pewter, &c. or entirely thrown away: and I remember having calculated some years ago, on the supposition of from one-half to two-thirds of the glass being abraded, that the loss of real glass at the London plate-house cannot be less than two tons per week, and the sand expended will weekly amount to at least sixteen or twenty tons.

A method has however been contrived of saving the whole of this refuse, and preserving it in a state

[68] These operations are conducted differently in France, as may be seen by consulting *Encyclop. ou Dict. Universel, Supp.* tome vi. page 647—654.

[69] It is the large quantity of iron that is contained in river sand which renders this ground glass so unfit for being formed again into plate-glass.

fit for being again formed into any of the best species of glass. It consists in grinding the plates with *pure flint*, instead of the river-sand hitherto employed; therefore, when the flints have been ground so as to have no admixture of iron with them, this residuum is very fit for the purpose above mentioned, and the glass contained in it may be estimated at more value than an equal weight of pure cullet[70]. In the operation of grinding the plates, three or four tons of prepared flints are equal in effect to 20 tons of sand; the work is done in much less time; and the abraded matter, instead of being a cumbrous and useless mass, is actually an estimable residuum, admirably adapted to the purposes of the manufactory, and capable of yielding considerable profit[71].

In resuming the subject, I have only to add, that when the grinding is finished, the next process is that of *smoothing*, which may indeed be considered to be a continuation of the grinding process; but this is performed by the hand, and with emery of different fineness, instead of sand.

Emery is imported in very hard solid lumps; these are ground by a powerful mill, and then sifted. The finer parts which pass though the sieve are se-

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[70] Cullet is a technical term for old broken glass.

[71] A patent has been taken out for this method of grinding plate-glass. It is dated 9th of August 1813, and the specification is printed in the 25th volume of the *Repertory of Arts*, Second Series, page 134.

parated into portions of different degrees of fineness, by a peculiar apparatus constructed for the purpose; but the effect is produced by a process somewhat similar to that of *elutriation*, an operation well known to chemists.

Emery, which is used for polishing metals as well as glass, is a native substance consisting of iron, alumina, and silica. It is brought from different parts of the continent, but it is found no where in such abundance as in the mountains on the western coast of the Island of Naxia, the most fertile of all the islands in the Archipelago. It occurs so plentifully there, that the adjoining cape has acquired the name of Cape Emery [72]. According to Mr. Boyle, its specific gravity is 400. From the analysis of Mr. Smithson Tennant, emery is composed of 80 parts of alumina, 3 silica, and 4 iron [73]. The emery which is used in making scouring paper has lately been much adulterated by the admixture of old bottle glass, which is ground fine for the purpose. The common sand-paper is covered with a mixture of this ground glass and sharp sand.

The last operation is that of *polishing*. This is done with colcothar of vitriol, and is a process of only a few hours. The plates are then well washed, and squared by a diamond for sale. Such are the processes by which that kind of plate-glass is made which is produced by blowing.

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[72] See Busching's *Geography*, vol. ii. page 154.
[73] *Philosophical Transactions* for 1802, page 400.

Little can be known of those manufactories where large mirrors are made by *casting*, as the proprietors have always conducted their works with the utmost caution and secrecy. There are, indeed, only two establishments of the kind that I know of; the one at the Castle of St. Gobin in the forest of Fere, in the department of the Aisne, in France, as before mentioned, and the other at Ravenhead near St. Helens, in the county of Lancaster. The buildings at St. Gobin are so various and extended, that they are said to resemble a large town more than a single manufactory[74]. They make plate-glass in France likewise by the process of blowing, similar to that of our manufactory at East Smithfield. One of these establishments is at Tour-la-Ville near Cherbourg, formed in the year 1665 under the patronage of Colbert during his administration, and designated by the name and style of "The manufactory for blown mirror-glass."

The manufactory at Ravenhead was established about the year 1771 or 1772, and the proprietors were incorporated by an Act of Parliament of the 13th of Geo. III. cap. 38, by the name and style of *The Governor and Company of the British Cast-plate Manufacturers*, with certain privileges and immunities which are accurately defined in the Act.

From this period a very considerable trade was carried on by this corporate body till the year 1794,

[74] See some account of this manufactory at page 180 of this volume.

when the Company was "compelled to sell their property for payment of their debts." These are the words of the Act of the 38th Geo. III. cap. 17. by which it also appears that the joint capital amounted to 60,000*l.* and the money borrowed to 67,535*l.* The establishment was afterwards purchased for the benefit of several persons who carried on the manufactory under the Act, until its expiration, and afterwards as a private company until the year 1798; when a new Company, consisting of eighteen most respectable individuals, was incorporated by an Act of the 38th of His late Majesty, entitled "An Act to incorporate certain persons for the purpose of continuing a manufactory of plate-glass." This Act bears date the 7th May, 1798, to continue for the term of 21 years, and from thence until the end of the then next session of parliament. The capital stock to be one hundred thousand pounds, and divided into shares of one hundred pounds each.

In consequence of the secrecy which has always been observed in the conduct of this manufactory, a detail of the various manipulations for the formation of cast plate-glass could hardly be expected. But since the first edition of these Essays went to press, I have been fortunate enough to be allowed to go through the whole of these very extensive works and to examine the various operations usually carried on there, and which I was allowed to see in consequence of my having taken the precaution to procure a letter of introduction from the Committee

in London, without which I understood the resident Managers would not have been justified in admitting me.

The first thing the attendant showed me, was the operation of grinding the plates, which is a concern of great magnitude. Those plates which are designed for mirrors and other purposes where the surface must be perfectly true, are firmly imbedded, in a horizontal position, upon a wooden table or platform, and these are made to revolve one upon the other by strong mechanical power obtained from a steam engine, and by these means they grind one another; sand and water being occasionally thrown in between them, and afterwards emery and water in a way very similar to the method already described at page 221 when treating on the manufacture of plate-glass by blowing. It is observable that the plates of glass are ground in pairs, and to see so many of these of several feet diameter in one room, moving in all directions by means of machinery and with considerable velocity, astonished me not a little.

When by this method the plates are ground to one uniform thickness, they are detached from the beds of plaster and removed to the polishing room. Here the process is performed by an article called *colcothar of vitriol*, which is merely sulphate of iron first calcined to redness and then reduced to an impalpable powder. This colcothar is spread upon a piece of hat-felt, which is attached to a very singular kind of machine kept in constant motion

by means of a powder communicated by the steam engine.

The last process of polishing is performed by the hand. This is managed by women, who traverse one plate of glass over the surface of another, with great velocity and adroitness. The article which is used in this finishing process is called *tutty*. It is the white oxide of tin finely levigated. This work being completed, the plates are well washed with water, and then taken to the cutting-room, where they are squared for sale, as described at page 224.

When I had examined these processes, the guide conducted me to the Foundry, which is the great room containing the melting furnaces, the table for casting, and the annealing ovens. The building containing all these is very lofty, and by far the largest room under one roof, that has ever yet been erected in Great Britain. It is 339 feet long, and 155 feet in width.

The furnace for founding the metal and the ovens for heating the crucibles, occupy a very long range in the middle of this immense room: they stand in a longitudinal direction, and fill up about one third of the whole area.

The method of heating the furnace is very important; but as I was not at the manufactory when this operation was performed, I am unwilling to attempt to describe it. The mode adopted at the Castle of St. Gobin is, however, too curious for a description of it to be omitted. Two persons stripped to their shirts run round the furnace without

making the least stop, and with a speed equal to seven leagues in six hours: as they go along they take up two small billets of wood, of about 1½ or 2 inches in diameter, which are cut for the purpose; these they throw into the first opening, and continuing their course do the same at the second, and at every other opening into the furnace. This circuit they continue without interruption for six hours successively, and then are relieved by others who continue the same course till the glass is completely finished. It has been thought surprising that the frequent application of two such small parcels of wood, and which are consumed in an instant, should keep the furnace to the proper degree of heat, which is such that a large bar of iron laid at one of the mouths of the furnace, becomes red-hot in less than half a minute[75].

At Ravenhead a row of annealing ovens stands on each side of the foundry, occupying the greatest part of the side walls of the building. These are each 16 feet wide and forty feet deep. The arrangement of these ovens is such that the plates of glass can be deposited in them immediately as they are cast, in order that they may cool as gradually as possible; and the floor of each is contrived to be on an exact level with the casting table, for the more easy removal of the plates into them. When each oven has received its destined quantity, it is

[75] *Supplement to the French Encyclopedia*, tome vi. Yverdon 1776, page 623. Rees's *Cyclopedia*, Article *Glass*.

shut up by an iron door, and this is secured all round with mortar to prevent any access of atmospheric air. The plate glass remains in these ovens about a fortnight, when it is taken out, and removed to the store-room. This process of annealing is one of the most important in the whole manufactory. If it were neglected, the plates of glass would be liable to crack at every change of temperature.

The most curious part of this business, however, is the process of casting the plate-glass, which is conducted somewhat in the following manner:—When the metal has been properly prepared and has become completely refined and settled, it is laded into smaller crucibles called cisterns, which stand in the same furnace. In these vessels it remains some hours longer, or until they become of a white heat throughout, which is one of the first criterions by which the workmen judge of its fitness for being formed into plates. When the glass has acquired that exact degree of temperature which has been found by experience to be best suited for its flowing properly under the roller, the crucible containing the fluid metal is taken out of the furnace by means of a crane and placed upon a low carriage for the conveniency of moving it to the casting table, which is sometimes a considerable distance from the melting furnace.

When the crucible of hot metal is brought near the table, it is raised by a crane with a pair of gallipers a few feet from the ground, to give the workmen an opportunity of scraping the scoria from the

bottom and outer sides of the crucible, which otherwise might drop off, and spoil the beauty of the plates. The pot of glass is then let down to the ground and the scum is very carefully taken off; it is then wound up again by means of the crane, and when at a sufficient height, is gently swung over the upper end of the casting table, where it is drawn on one side, and by a peculiar contrivance for throwing the crucible into an inclined position, a torrent of melted glass is suddenly poured out on the smooth iron surface beneath it. The crucible is no sooner emptied of the metal, all of an intense red-heat, than the iron roller is set in motion, and by this massive instrument the whole of the glass is spread out into one single sheet of a great size, and of an uniform thickness; the thickness of the plate being determined by ribs of brass which are fixed one on each side of the casting table, and upon which the iron roller runs. The length of each plate is however in some measure determined by the quantity of metal which the crucible happens to contain; and if it should have held more than was absolutely necessary for covering the surface of the table, the extra quantity falls into a vessel of water and is employed in the next operation.

The spectacle of such a vast body of melted glass poured at once from an immense crucible on a metallic table of great magnitude, is truly grand; and the variety of colours which the plate exhibits immediately after the roller has passed over it, renders this an operation far more splendid and interesting

than can possibly be described. Indeed the effect which it produces is quite inconceivable to such as have not been eye-witnesses of the manipulations in this surprising establishment.

Notwithstanding the immense scale upon which the manufactory in Lancashire is established, it appears to me, that it differs from the one in London more in the circumstance of the plates being *cast*, than in the composition of the glass itself.

From information which I have received by various channels, I apprehend the founding the metal is the same at both places; but that at Ravenhead, when the metal is made ready it is removed into other receptacles called cisterns, as already mentioned, and so contrived that they may be readily hoisted out of the furnace when every thing is in a state of preparation, and the fluid body poured from them *at once*, and as quickly as possible, upon the table, where the plate of glass is ultimately formed.

This table formerly consisted of one massive plate of copper twelve feet long and of a proportionate width, ground and polished so as to present throughout an uniformly smooth surface. It was soon found, however, that copper is an improper metal for the purpose, it being liable to crack from the sudden transition of the heat from the torrent of melted glass poured upon it.

Several copper tables having been thus rendered useless, and a vast expense incurred in substituting one new copper table after another, the managers at length came to the determination of trying iron,

and accordingly a cast-iron table of great thickness was forthwith prepared for the purpose. This immense mass of iron weighed so many tons that it was necessary to build a peculiar kind of carriage to transport it, and the other expenses of conveying it from the iron foundry to the glass works were enormous. This table, like the former ones of copper, was fixed upon a suitable frame, and this is supported by casters, for the convenience of moving the table from the mouth of one annealing oven to another.

Whether it must be attributed to the extra thickness of this metallic table or to any other cause, it may be difficult to determine; but this certainly answered the intended purpose, and appears to have sustained no injury whatever from the frequent and sudden accessions of heat to which it has been exposed. When I saw it, it had been in constant use for some years, and I was told that the proprietors thought it would last for any length of time that they could possibly require it.

It should have been remarked, that as soon as these plates have become fixed by cooling, they are thrust by main strength off the table and gradually slipped into the annealing oven immediately contiguous, and there they are treated like the smaller plates already described, excepting in one circumstance, that of their being spread out, one by one, in a horizontal position, instead of being piled on their edges, as they usually have been in those works where plate-glass is made by blowing.

The reader may conceive the advantage which must result from this arrangement, when the vast size of these plates is considered. The method of blowing answers extremely well for small plates, or for plates which do not exceed 4 feet in length and 2 feet 3 in breadth; but when larger, they have not a sufficient thickness to bear the grinding, and besides, no man could have strength sufficient to wield in his arms that quantity of glass which is required to form such immense plates as are made at Ravenhead.

How very advantageous it is to the Company to sell *large* plates, may be seen in the following table, which I have formed from a tariff of the prices of the different sized polished plates of glass, which was published and sold by the booksellers in 1794, in a small volume of 100 pages. The first column contains the number of square feet in each plate, and the opposite ones their respective prices, unsilvered.

Feet.	£.	s.	d.
6	4	0	0
12	14	5	0
20	36	14	0
30	74	11	0
42	156	12	0
48	225	10	0
54	306	4	0
60	395	0	0

The proprietors of this establishment announce however, by public advertisement, that they have constantly on sale at their warehouse, Blackfriars

Bridge, London, glass-plates of the enormous size of six feet by twelve feet each.

That one plate should contain more than seventy square feet of glass, and yet have a surface perfectly true, is really astonishing; and when we consider that there is only one establishment in the world that can at all compare with the works at Ravenhead, we need not hesitate in pronouncing the latter to be the most curious and interesting manufactory in the British empire.

In concluding the account of the manufacture of plate-glass, it must be noticed that the great expenses necessarily attendant upon the making of *cast* plates have obliged some of the artists in France to return to the old method of blowing; and some have been so fortunate in improving this branch of manufacture, that plates are now formed in that country, by blowing, which are 64 Flemish inches in height and 23 in breadth, (in English measure 60 inches by 21½ inches,) a size which it had been impossible to attain before, except by the process of casting. The mass of matter necessary for this purpose, weighing more than a hundred pounds, is by the workman blown into the shape of a large bag; it is then reduced to the form of a cylinder, and, being cut up, is by stretching, rolling with a smooth iron, and other means not yet known but to those employed in the art, transformed into an even plane[76].

[76] Beckmann's *History of Inventions*, vol. iii. page 207.

Having thus briefly described the modes of making the five different species of glass, it may be proper to advert to a recent discovery in the art, and then to say a few words on the properties of glass itself.

The discovery to which I refer is that of glass incrustations, for which a patent has been obtained under the name of *Crystallo-Ceramie*, by Messrs. Pellatt and Green of St. Paul's Church-yard, London[77]. In describing this elegant and ingenious manufactory, I cannot do better than avail myself of Mr. Pellatt's own memoir on the subject.

The ancients were not altogether ignorant of this art; but their incrustations were very imperfect in consequence of their not being in possession of a substance for forming the device or figure to be inserted within the body of the glass, that was less fusible than the glass itself.

About forty years ago, a manufacturer in Bohemia attempted to incrust in glass small figures made with a peculiar kind of clay; but his experiments were in but few instances successful, in consequence of the clay not being adapted to adhere properly to the glass. It was, however, from the Bohemian that the idea was caught by some French manufacturers, who, after having expended a considerable sum in the attempt, at length succeeded in incrusting several medallions of Buonaparte, which were

[77] See a *Memoir on the Origin, Progress and Improvement of Glass Manufactures: including an Account of the Patent Crystallo-Ceramie, or Glass Incrustations.* Quarto, London 1821.

sold at an enormous price. From the extreme difficulty of making these medallions, and their almost invariably breaking, very few were finished; and I understand that the French have since then contented themselves with confining the art to the decoration of small trinkets, &c.

A patent has, however, as before mentioned, been recently taken out in this country for making these ornamental incrustations; and if we may judge from the manner of their execution, they promise to produce a new era in the art of glass-making. By this process, ornaments of any description, heraldic crests, or portraits of any variety of colour, may be introduced into the glass, so as to become perfectly imperishable. It must be understood that the substance of which these devices are composed is *less* fusible than glass, incapable of generating air, and at the same time susceptible of contraction or expansion, as, in the course of manufacture, the glass becomes hot or cold. The ornamental figures are introduced into the body of the glass *while hot*, by which means they become actually incorporated with it.

The composition used in the patent incrustations, and which does great credit to the taste and chemical acquirements of Messrs. Pellatt and Green, is of a silvery appearance, which has a very superb effect when introduced into richly cut glass. And as miniatures and other paintings may be enamelled upon it, without the colours losing any of their brilliancy, it may be adapted to any purpose that the taste or judgement of the artist may suggest.

A most important advantage to be derived from this elegant invention, respects the preservation of dates and inscriptions. Casts of medals and coins present no equal security for perpetuating them. Had this art been known to the ancients, it would have preserved to us many interesting memorials. The inscription, when once incrusted in a solid block of crystal, like the fly in amber, will effectually resist for ages the destructive action of the atmosphere.

In reverting to the nature of glass as a chemical compound, it may be said that glass possesses several distinct and very remarkable properties which may be enumerated in the following order. It is transparent and elastic, it possesses strong electrical powers, is ductile and fusible by heat, becomes very brittle by sudden change of temperature, and is imperishable in the fire. Dr. Merret has enumerated no less than 26 distinct properties which glass possesses, some of which were new to me and curious[78].

It is the *ductility* of glass which qualifies it for being fashioned into such numerous shapes and employed for such a variety of purposes. Dr. Merret says, that when James Howell was at Venice he saw a complete galley, with all her masts, sails, cables, tackling, poop, forecastle, anchors, and her long boat, all made in glass[79]. Cardan

[78] See page 214 of his Translation of *Neri's Art of Glass.*
[79] Translation of *Neri on Glass,* page 314.

relates that he saw a cart with two oxen in it, made with glass, and yet small enough to be covered with the wing of a fly[80].

The transparency of glass is not a little surprising, when we consider that it is formed of substances which in themselves are perfectly opake.

It was the *transparency* of glass which occasioned it to be so much esteemed by the ancients. The emperor Nero paid 6000 sestertia, nearly equal to 50,000*l.* sterling, for two small transparent glass cups with handles[81]. Glass not transparent was then in common use for various domestic utensils, also a red coloured opake glass called *vitrum hæmatimon*, probably from *hæmatitis* the blood stone[82]. Some of the windows in the ancient city of Pompeii were glazed with a thick sort of glass, but this was only semi-transparent[83]. Martial, however, mentions glass in such a manner as shows it to have been common in his time for drinking vessels, and also of so transparent a texture as to admit an accurate examination of the liquor contained in them[84].

"Nos bibimus vitro, tu myrrha Pontice: quare?
Prodat perspicuus ne duo vina calix[85]."

There must, indeed, have been a considerable

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[80] *De Varietate*, lib. x. cap. 52. [81] Pliny, lib. xxxvi. cap. 26.
[82] Pliny, lib. xxxvi. cap. 67.
[83] Miss Starke's *Letters from Italy*.
[84] On the knowledge of the ancients respecting glass, see Dr. Falconer in the *Memoirs of the Literary and Philosophical Society of Manchester*, vol. ii. page 95—105.
[85] Mart. *Epig.* iv. 86.

number of makers of glass, in ancient Rome; for we read of their having a district near the Appian gate assigned them for carrying on the manufactory. The elasticity of glass may be proved by a pane of common window-glass, which may be bent out of a straight line and yet will return again to its place without being fractured; and if glass be run out very fine like a thread, it may be folded round the finger without breaking.

One of the most elastic of all known bodies is glass. If it be drawn into fine strings, it may be bent into a complete circle, and held in that position for any length of time without impairing its elasticity; for the moment the pressure is removed it recovers its form, and becomes a straight rod as before.

A few years ago a person travelled through most of the counties of England to exhibit the spinning of glass. He would spin many hundred yards of it, and as fine as silk, in a minute.

In consequence of the ready excitability of glass by friction, and its impermeability to electricity, it is the only material which is now made use of for the construction of electrical cylinders.

Unannealed glass possesses some very singular properties. Vessels of capacity made with such glass will often bear a considerable blow from without, and yet be shivered to pieces by the smallest fragment of stone, even less than a pea, if dropped in the inside; and the thicker the bottom the more easily will the effect be produced. Cups of green

glass, some of them three inches thick at bottom, and which had borne the shock of a musket ball dropped from a considerable height, were shivered into fragments by letting a bit of flint weighing only two grains drop into them [86].

The brittleness which glass acquires by sudden change of temperature, and its indestructibility in the fire, are properties which alone might furnish matter for many interesting observations, and much curious speculation, to one who would undertake to write entirely on this subject; but the size to which this essay has already attained will oblige me to pass on to enumerate some of the principal desiderata in glass-making, preparatory to a few desultory hints which I propose to offer, and which I presume may be worthy of the consideration of all who are engaged in this important though at the same time hazardous undertaking.

The most obvious desiderata in the manufacture of glass appear to me to be the following, viz.

First. To discover an easy and effectual method of examining the different kinds of clay, and determining which is most suitable for the manufacture of the furnaces and crucibles.

Secondly. To ascertain the best form of the various sized pots or crucibles, as well as the thickness required in each according to its magnitude, for supporting the pressure of the melted glass at the different varieties of temperature.

[86] See the *Philosophical Transactions*, Nos. 475, 509, & 515, and the *Dublin Literary Journal*, 8vo. 1746, vol. iii. page 154.

Thirdly. To devise a better and more certain mode of moulding the crucibles, so that they shall not be liable to burst during the formation of the glass.

Fourthly. To prepare glass by some method which shall dissipate the gaseous products completely, and at the same time unite the materials more uniformly and with greater certainty than has ever yet been done by any of the modes already practised.

Fifthly. To make glass with the muriates of potash and soda, without the previous decomposition of these salts, and of as good quality as that which is made with the carbonates, sulphates, and sulphurets of those alkalies.

Sixthly. To discover some preparation of pit coal, or other combustible materials, which shall produce as great a degree of heat and flame in the furnaces as wood, and yet be as fit in every other respect for making glass.

Seventhly. To anneal glass more effectually and with greater certainty than can be done by the methods usually adopted for that purpose.

Eighthly. To devise some new mode of charging the duty on glass fairly and *bonâ fide* on such glass only as shall be saleable, so as to relieve the manufacturer from the interference of excise officers, during the time of operation, and which shall leave him at full liberty to melt and remelt the materials, to make experiments, or to institute new processes whenever he may see occasion, without his render-

ing himself liable to the operation of any penal statute.

On these several desiderata, the following observations present themselves.

It has been determined by Loysel that an argillaceous earth which contains at least 95 per cent. of quartz and alumina, and less than 5 per cent. of carbonate of lime and oxides, may be employed in most of the small white glass works, where the fire is not very intense; but that the proportion of alumina and quartz ought to be 97 in each 100 pounds when it is to be employed in the great furnaces for plate and bottle glass, especially for the fabrication of the crucibles [87].

The same writer states, that the materials of which these are made ought to be infusible in the degree of heat which is necessary to be employed; not susceptible of corrosion by the action of the mixtures in fusion, and capable of taking and preserving those forms which are found to be most suitable for these constructions [88]. The best directions that have ever been given on the necessary thickness of the crucibles are to be seen in the same work [89]. Some experiments on this subject having been made by him, he formed a valuable table for the use of the manufacturers of glass, to show the respective thickness of the crucibles of various diameters, all which are estimated according

[87] Loysel, *Essai sur l'Art de la Verrerie*, page 16.
[88] Ibid. page 5. [89] Ibid. page 58.

to the different degrees of the tenacity of the materials[90].

In addition to the various remarks which I have made on the construction of the crucibles, I am desirous of annexing the following important observations.

"Pottery," says Loysel, "is one of the most difficult and delicate parts of the art of glass-making, and merits the strictest attention. If the pottery is perfect, the artist has the power to manage the action of the heat, to vary at pleasure the vitrifiable compositions, to regulate the melting, the refining, and the whole works. He knows beforehand the products of his fabrication, and directs it to his greatest advantage. If on the contrary the pottery is bad, all is confusion. The first cost of the materials, their preparation, and the expense of the workmanship, turn to entire loss, and the ruin of the proprietor is inevitable. No expense therefore, or care, ought to be spared to procure good pottery[91]."

The English glass-makers labour under an inconvenience which is not felt in France and some other countries on the Continent of Europe. In consequence of their heating their furnaces with pit-coal they are under the necessity of making their best flint glass in *covered* pots; and as the heat is much lower in the interior of a covered crucible than in an open one, we are obliged to make our

[90] Loysel, *Essai sur l'Art de la Verrerie*, page 269.
[91] Ibid. page 57.

glass of more fusible materials; and consequently, by using a large portion of lead, and less silica, we produce a softer glass than is prepared by those who have an abundance of wood fuel.

It appears to me that there can be no certainty in the process of annealing without the use of a pyrometer; and as the glass manufacturers have frequently to make experiments on clays, have not such persons excellent opportunities of contriving such an instrument as would suit not only this purpose, but serve for the large furnaces also? Glass made with alkali and silica only, is more difficult to anneal with certainty than such as contains lime and lead in its composition.

It was formerly a common notion that soda was better calculated for making glass than potash: but of late years this appears to have been doubted; for many eminent glass-makers now say that they can make as good glass with potash as soda. The ancients made use of soda for the formation of glass. The mixture of sand and soda, before it became perfect glass, was called *ammonitrum*. I am, however, of opinion that soda is preferable for glass, inasmuch as it requires more silica for its saturation than potash; and it will not be denied that the greater the quantity of the siliceous earth which can be made to enter into the composition of glass, the harder will that glass be, and the less liable to be injured by abrasion. This extra power of saturation holds good also with the acids, for 100 parts of soda combine with 173 parts of dry nitric

acid, 128 parts of solid sulphuric acid, or 88 parts of dry muriatic acid; whereas potash takes up only 114 parts of nitric, 84 of sulphuric, or 58 parts of muriatic acid.

In making glass, "if the combination be such that in 1000 parts there remain only 200 or even only 150 parts of alkali, the glass is hard, clear, brilliant and transparent, and approaches the beauty of rock crystal. The excellence of flint glass is in direct ratio to the quantity of silica, and in inverse ratio of the quantity of alkali [92]."

Moreover, soda, as was before mentioned, will make a more fluid metal, and thus the manufacturer will at all times be more likely to separate all the sandiver, for this rises with more difficulty to the surface when the glass is made with potash; and it is well known that, wherever any of the sandiver or glass-gall remains in the finished glass, it will occasion striæ, clouds or bubbles, either of which very much lessen its value.

When plate-glass is to be made with potash, it is generally thought requisite to add some borax to the composition to render the metal more fluid, otherwise it is apt to stiffen before the plates can be completely formed. This is another objection to the use of potash for this particular species of glass. On these accounts it is of importance always to use soda for plate-glass, and also for such flint glass as is intended to be employed for par-

[92] Loysel, *Essai sur l'Art de la Verrerie*, page 113.

ticular purposes; especially for such articles as are equired to sustain much wear.

It is however generally imagined that potash will make the *whitest* glass, though such glass is more apt to be *seedy*, as the workmen call it, that is, to be full of very minute specks, which greatly impair its beauty, and diminish its value.

A friend of mine in the glass trade has however assured me that he never could make flint glass, even with the purest soda, so perfectly white as he could with pearl-ash, though he repeated the experiment many times and with every precaution.

Since then I have had an opportunity of examining several specimens of flint glass made with soda and others with potash; and I am now inclined to think that very brilliant flint glass, perfectly pellucid and colourless, cannot be made with soda, but that potash is absolutely necessary for this particular species of glass. The potash ought however to undergo a complete purification from all neutral salts, before it be employed for wine glasses or for any kind of ornamental flint glass.

It may in some cases be safer to use soda, because, where too much alkali has been employed, such glass will be less likely to be injured by exposure to the atmosphere in damp situations than glass made with the vegetable alkali, which is always liable to deliquescence. I am, perhaps, justified in this observation by a remark of Dr. Merrit, in his examination of Neri's Art of Glass. "In old windows of French glass, in that part,"

says he, "which lies towards the air, you may discern pieces of salt; and in the finest glass, where there is a great proportion of salt to the sand, you shall find that such glasses standing long in subterraneous places, will fall to pieces, the union of the salt and sand decaying." Fourcroy also says, that glass made with soda is best for holding the mineral acids, as such glass is decomposed with more difficulty by acids than such as is made with potash [93].

Borrichius relates, that he saw several glass lacrymatories dug up at Rome which had lain in the ground several hundred years, and that the glass was split into an infinite number of laminæ like the Muscovy talc, and yet these laminæ were smooth and transparent [94]. This effect was probably occasioned by the use of potash in the glass, and the employment of too large a quantity of that alkali.

I would not, however, in these remarks be misunderstood; for it is impossible to be sure of having perfect glass unless an extra quantity of alkali be employed: but then care must be taken to prolong the process till the whole of this excess be separated from the mass and volatilized.

Shaw has a remark to the same purpose. "In order," says he, "to give our glass the desired degree of hardness, it is proper to continue it long in the fire, which is constantly found to add strength

[93] Fourcroy's *System of Chemistry*, vol. ii. page 387.
[94] Borrichius *de Ortu et Progressu Chemiæ*.

and hardness to glass. Common glass, by being constantly kept in a strong fusion for a month or six weeks, has become of a stony hardness, approaching to the native hardness of the flint or sand employed in its preparation[95]."

I am rather surprised that *sulphate of soda* has not been more employed in this manufacture; because, if this salt be fused with plenty of carbonaceous matter, it will soon be converted to a sulphuret; and when in this state, the heat of the furnace, combined with the affinity which the alkali has for the silica, would separate the sulphur entirely, and leave the alkali as capable of combining with the siliceous matter as if it had originally been pure soda.

It is necessary to remark that in this case an abundance of charcoal must be used, because, if any undecomposed sulphate of potash or sulphate of soda be left in the glass, it will form what are called *salt-blisters*.

In like manner, I apprehend, American potash might possibly be employed instead of pearlash; for, though more contaminated with sulphur, this would be separated by the heat of the glass-house furnace, and the result would be advantageous; inasmuch as potash is usually cheaper than pearlash, and yet contains more alkali. There can, however, be no doubt that potash would do equally well for decomposing common salt, because much of its impurity would be separated in that opera-

[95] Shaw's *Chemical Lectures*, page 427.

tion, and the remainder would be got rid of in the process of fritting the glass.

I have also to recommend that frequent attention be paid to the price of salt-petre, because I am persuaded that whenever this article is at a low rate it must be advisable to employ it for flint and crown glass in preference to American pearlash; inasmuch as it contains a large portion of alkali, and is free from those neutral salts with which pot- and pearl-ash of every kind are contaminated. Where metallic oxides have been employed to colour glass, either for windows or for the imitation of the precious stones, nitre is found to be of great use, as it tends to preserve the metallic oxides in a high state of oxidizement, and thus imparts great vivacity to the colours. Nitre is composed of 47 per cent. pure potash and 53 per cent. of dry nitric acid.

Agricola knew the value of nitre in making glass. "The first place," says he, "must be given to salt-petre, the second to fossil salt [96]."

It has been said that borax (subborate of soda) will make a harder glass than either of the pure alkalies. Borax consists of 34 parts of boracic acid, 17 parts of soda, and 49 parts of water [97].

This saline substance was known to the ancient Romans. We read of the Circus in the time of one of the early Cæsars being covered with vermilion and *borax* [98]. Whether borax or *tincal* could

[96] Agricola *De Re Metallica*.
[97] Bergman.
[98] Suetonius *in Vita Caligulæ*, § 18.

be procured in quantity cheap enough to be employed in glass-making, I know not. Dr. Shaw relates, that with four ounces of borax and one ounce of fine white sand he formed a pure glass, which was so hard that it cut common glass like the diamond[99].

It would be advantageous, I conceive, if some method could be devised of frequently stirring the fluid metal in the crucibles, so as always to ensure the production of glass that shall have a perfectly homogeneous character. In a former part of this Essay I have mentioned the circumstance of veins or striæ appearing in flint glass. These might generally be prevented by the adoption of the expedient which is now suggested, because they arise from the want of due uniformity in the mixture of the compound mass. Mr. Keir, the translator of Macquer's *Chemical Dictionary*, and who was himself formerly engaged in the manufacture of glass at Stourbridge, says, "The reason why flint glass is more subject to veins than any other glass is, because it is composed of materials of more different densities[100]."

Loysel has shown that the various specific gravities of the different compounds which are formed, such as those with alkali and silica; alkali and clay; and, lastly, alkali with the metallic oxides; are fully sufficient to account for the production of

[99] Shaw's *Chemical Lectures*, page 426.

[100] See his note in vol. iii. of the Dictionary, under the article *Vitrification*.

these imperfections, and that nothing but a more uniform mixture of the different materials, together with complete fusion, can prevent their appearance.

"Glass made at a great degree of heat will always be lighter than that made at a lower temperature. The first contains more silica and less alkali, whereas the specific gravity of glass augments according to the greater quantity of alkali that is combined with it." "Glass made to contain 80 silica and 20 alkali will have a specific gravity of 2.36, whereas that which is composed of 54 silica and 46 alkali will be 2.54."[101] Might it not be advisable for the proprietor of every glass-house to take the specific gravity of each pot of metal when finished? as this would always be a guide to show whether the workmen had observed due care in keeping the furnace at a proper degree of temperature.

In treating this subject, Loysel remarks, that "glass made with silica and the fixed alkalies has a specific gravity of 2.3 to 2.4; that formed with alkali and clay 2.5; that with alkali and chalk 2.7 to 2.8; the oxide of manganese if vitrified by itself 3.2 or 3.3; while the glass made with oxide of lead will be 7.2 to 7.3 of specific gravity." When these different kinds of vitrified products occur in the same crucible, and a complete mixture of them has

[101] Loysel, *Essai sur l'Art de la Verrerie*, page 207.

not been effected, it is not surprising, he observes, that the glass should be imperfect [102].

The art of making glass seems to depend upon the successful or perfect union of two or more metallic oxides which have an affinity for each other. On this principle it is that potash, an oxide of potassium, and silica, the oxide of silicium, are fused together and form glass. One part of silica and two parts of borate of soda unite and form a transparent colourless glass. One part of silica and three of oxide of lead form good green glass, and it is well known at all the iron furnaces that silica, when united to the oxide of iron, produces a perfect black glass of extreme hardness and durability.

I have only one observation more, viz. that the proprietors of the respective manufactories we have been describing, ought, in the construction of the furnaces and the fabrication of the crucibles, to wave all considerations of economy in the expenditure, because no sacrifice can be too great to obtain such as will constantly sustain a very elevated temperature without injury. It has been already shown [103], that where glass is to be made with the least possible quantity of alkali, a high degree of heat must be employed, and it is indeed on this circumstance that the economy of glass-making seems chiefly to depend.

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[102] *Essai sur l'Art de la Verrerie*, Loysel, page 183.

[103] See an observation on temperature, page 209.

The principal Acts of Parliament now in force respecting the manufacture and sale of glass, are as follow—viz. 19th Geo. II. chap. 12; 17th Geo. III. chap. 39; 24th Geo. III. chap. 41; 35th Geo. III. chap. 114; 38th Geo. III. chap. 33; 38th Geo. III. chap. 89; and the 43d Geo. III. chap. 69. In the 53d Geo III. an Act passed, intitled " An Act for allowing glass makers to dispose of the muriate of potash arising in the manufacture of flux for glass, and for charging a duty of excise of 20*s*. per ton thereon, to take date from the 5th day of July, 1813."

evident from the great progress which it had made in the beginning of the Christian era[3].

That the ancients had learnt some method of rendering their linen extremely white, may be supposed from many remarks which are interspersed among their writings. Homer speaks of the garments of his countrywomen in a way that leaves no doubt of their being clothed, occasionally at least, in *white* vestments.

> "Each gushing fount a marble cistern fills,
> Whose polish'd bed receives the falling rills,
> Where Trojan dames, ere yet alarm'd by Greece,
> Wash'd their fair garments in the days of peace[4]."

There is however a passage of Pliny, an author whom I have often quoted, and who published his Natural History in the first century, which to me appears perfectly conclusive.

"Of late days," says he, "there were seen in the amphitheatres of the Emperor Nero, fine curtains of blue azure colour like the sky, and the very floor of the ground under men's feet, was coloured red. But for all these paintings and rich dyes, yet when all is done, the white linen held the pre-eminence still, and was highly esteemed above all colours[5]."

Pliny has likewise informed us, that the Gauls

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[3] A writer of the first century, speaking of linen garments, says, "The fine lawn made from the flax called *Byssus*, whereof our wives and dames at home set so much store by, for to trim and deck themselves, groweth in Acaia, and I find that in old times it was sold as dear as gold." Holland's *Pliny*, vol. ii. p. 5.

[4] Pope's *Iliad*, book xxii. line 201.

[5] Holland's *Pliny*, vol. ii. p. 5.

and Britons of his time were acquainted with a method of bleaching linen cloth, and he thus describes their process. "After the flax is spun into yarn it must," says he, "be bleached and whitened by being pounded several times in a stone mortar with water: and lastly, when it is woven into cloth, it must be beaten again upon a smooth stone with broad-headed cudgels, and the more frequently it is beaten it will be the whiter and softer[6]." The same author tells us that they sometimes put the roots of wild poppies into the water, to make it more efficacious in bleaching linen[7]. "There is a kind of poppy (says he) much sought after for bleaching linen cloth; for, being scoured therewith, it is wonderful how white and pure they will look. And yet people are grown to this disorder and vain enormity, that they have essayed to stain and dye their linen into other colours, as well as their woollen cloths[8]."

We learn from Theophrastus, who was the son of a fuller in the Isle of Lesbos, and who wrote 300 years before Christ, that lime was then employed in bleaching. He relates, that a ship partly loaded with linen, and partly with lime for bleaching it, was destroyed by the accidental access of water to the lime.

Although it should be proved that the bleaching of linen is a process of very great antiquity, it must not, however, be supposed that any people

[6] Pliny's *Hist. Nat.* lib. xix. cap. 1. § 9.
[7] *Ibid.* lib. xx. cap. 19. § 2. [8] Holland's *Pliny*, vol. ii. p. 5.

were acquainted with it in the earliest stages of their society, or before they had acquired some degree of civilization.

The vestments of the early inhabitants of the world discovered neither art nor industry. They made use of such as nature presented, and needed the least preparation. Some nations covered themselves with the bark of trees, others with leaves, or bulrushes, rudely interwoven [8]. The *skins* of animals were also universally used as garments, worn without preparation, and in the same state as they came from the bodies of the animals [9].

In process of time recourse was had to the *wool* of animals [10], and this led to the further discovery of the art of uniting the separate parts into one continued thread, by means of the spindle; and this would consequently lead to the next step, the invention of weaving, which, according to Democritus, who flourished four hundred years before Christ, arose from the art of the spider, who guides and manages the threads by the weight of her own body [11]. That the invention of weaving was long prior to the time of Democritus, appears from the sacred writings [12].

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[8] Strabo, lib. xi. p. 781. Senec. *Epist.* xc. p. 406.

[9] Lucretius, lib. vi. ver. 1011. Pausanias, lib. xx. c. 38.

[10] Fifteen hundred years before the Christian era, the people of Palestine knew the value of the fleece of their sheep, and had regular seasons for collecting it. See *Genesis*, xxxi. 19, and xxxviii. 12—14.

[11] Goguet, vol. i. p. 125.

[12] See *Genesis* xiv. 23. The original is, "a thread of the *woof*." Also see *Genesis* xxiv. 65.

After the art of weaving had been invented, it was probably not long before flax, hemp, and cotton, were employed in the fabrication of garments, especially as the President Goguet has abundantly proved that vestments of cotton were in use in the Patriarchal ages [12]; and there can be no doubt that in the time of Christ several nations had acquired great proficiency in the manufacture of linen cloth.

Pliny describes, as growing in the higher parts of Egypt, the cotton shrub of which cloth was made; and "of which," he says, "the Egyptian priests were wont to have *surplesses*, in which they took a singular delight [14]." He also tells us [15] that vestments of cotton were worn by the ancient Egyptians; and more than a thousand years before the commencement of the Christian era, Moses speaks of robes of linen, and commands his people "not to wear a garment of divers sorts, as of woollen and linen together [16]." The dress of the ancient Babylonians consisted of a tunic of lawn, which they wore next to their skin. It descended, in the eastern mode, to their feet [17]. The Athenians wore long robes of fine linen dyed purple [18].

It is not likely that the materials of which we have been speaking were long employed in the manufacture of garments, before some method was adopted of improving their colour by artificial

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[12] Goguet, book ii. p. 127.
[13] Pliny, lib. xix. § 2.
[14] Holland's *Pliny*, vol. ii. p. 3.
[15] *Deuteronomy* xxii. 11.
[17] Goguet, vol. iii. p. 187. Herodot. lib. i. n. 195.
[18] Thucyd. lib. i. p. 6. n. 6.

means, as has been already hinted. This will appear still more probable, when we consider that some of the early inhabitants of the world had several methods which in themselves tended very much to whiten linen and cotton cloth.

The evidence of Pliny is alone sufficient to prove the truth of this assertion. "The Faventine cloth," says he, "is always far whiter than the Allian, which is ordinarily brown when it is new woven, and before it be bleached. The Retovine linen is exceeding fine; the thread itself is more even (if evener may be) than that which the spider spinneth." "I myself have seen so fine and small a thread of Cumes flax, that a whole net knit thereof, would pass through the ring of a man's finger. I have also known one man carry so many of them (easily) as would go round and compass a whole forest [19]."

There is a passage in Job, the most ancient book extant, in which the writer speaks of washing his garments in a pit with the herb *Borith*, which was probably a plant that furnished an alkali [20]. Homer describes Nausicaa and her companions washing their clothes by treading them with their feet [21]; and according to Pliny, the ancient Greeks and Romans were acquainted with the detersive

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[19] Holland's *Pliny*, book xix. chap. 1.

[20] See *Job* ix. 30. The Hebrew text has *Bor*; but the best commentators think it is the same with the *Borith* of Jeremiah ii. 22. and of Malachi iii. 2. The latter of these passages our translators have rendered *Fuller's soap*.

[21] *Odyss.* lib. vi. ver. 92

properties of several kinds of earth[22], as well as of several plants, which they employed in scouring linen[23].

In like manner, throughout France and some other parts of the Continent, the vegetable called Wake Robin or Cuckowpint, the *Arum maculatum* of Linnæus, was formerly much used in bleaching. The juices of this plant are said to have the property of dissolving the resinous colouring matter, and rendering the cloth white[24].

In the passage of Homer, in which he describes the princess Nausicaa and her damsels washing the robes of state for her intended nuptials, it appears that they were acquainted with the bleaching power of the atmosphere. Indeed the President Goguet supposes that all the linen and cotton dresses of ancient times were washed and bleached daily[25]. The passage is translated by Pope with spirit; but he has omitted the circumstance of their treading the garments with their feet. This is the narrative.

" They seek the cisterns where Phæacian dames
Wash their fair garments in the limpid streams;
Where gathering into depth from falling rills,
The lucid wave a spacious bason fills.
Then emulous the royal robes they lave,
And plunge the vestures in the cleansing wave;

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[22] For an account of the particular kind of earths which the Romans employed in bleaching, see Pliny, cap. 100.

[23] Pliny, lib. xxxv. § 57; lib. xxvii. § 88.

[24] Dr. Lewis's *Neumann*, vol. ii. p. 226.

[25] Goguet, vol. ii. p. 110.

(The vestures cleans'd o'erspread the shelly sand,
Their snowy lustre whitens all the strand;)
Then with a short repast relieve their toil,
And o'er their limbs diffuse ambrosial oil;
And while the robes imbibe the solar ray,
O'er the green mead the sporting virgins play;
They sport, they feast; Nausican lifts her voice,
And warbling sweet, makes earth and heaven rejoice."

I would not lay too much stress on the evidence afforded by this passage, as Mr. Pope has made use of some epithets which are not warranted by the original. The Scriptures, however, contain ample testimony of the use of linen garments in times of remote antiquity.

Having hazarded these few introductory remarks, it may perhaps be convenient to divide the subject itself into two parts, consisting of the European methods of bleaching before the discovery of chlorine gas, and of the practices which have been adopted since that period. I shall then conclude this Essay with a brief account of some of the present most important desiderata in bleaching, accompanied with such hints or proposals which, on a chemical review of the subject, may suggest themselves as proper to be submitted to the consideration of practical men.

Half a century ago the linens of Holland were the most esteemed of any in Europe, and this arose in a great measure from the superior skill of the Dutch in bleaching. An account of the process in the great work at Haarlem, and which I copy from a scarce book, printed in the year 1754, en-

titled "*Select Essays on Commerce, &c.*," will therefore, I trust, not be uninteresting to the modern bleacher.

"The whitening grounds of Haarlem," says the author, "are situated about a league from the city gates, and the most considerable of all is in the neighbourhood of the village Bloemendaal. The cause of the wonderful whiteness in the Dutch cloths is ascribed to the lye-ashes of Muscovy, and to the water of their downs; which is nothing else than sea-water[26], which, filtrating through the downs and mountains of sand, bursts out perfectly sweet and clear.

"When a piece of linen is to be bleached, it is in the first place steeped in a lixivium or lye, where other cloth hath been trod; afterwards it is trod in a new lye of lye-ashes[27], poured upon it boiling hot. This is boiled in large copper caldrons, and is never poured upon the cloth till it is as clear as wine. The linen is left eight days in this lye, after which it is washed and pressed in this manner.

"They empty some buckets of butter-milk into wooden vessels fixed in the ground[28]; then they throw in a piece of linen, which three men tread

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[26] A prejudice formerly existed on the Continent, that no perfect bleaching could ever be performed on grounds that are situated at any very considerable distance from the sea.

[27] Soon after the introduction of bleaching into this island, the Dutch monopolized the pearl-ashes of Europe, and the two merchants who bought them, afterwards supplied this country at double or triple the original price. Home *on Bleaching*, p. 16.

[28] See Essay VII. vol. i. p. 477.

with their feet as much as possible. Afterwards they pour in more butter-milk [29], and then another piece of cloth, proceeding thus alternately till the vessels are nearly filled, when they lay planks over the linen, upon which they raise a large round piece of wood, or great stake, touching the lower side of a beam, between which and the stake they drive wedges, to press the cloth. Six or seven days after, they take the cloth out of these vessels; and if it be not white enough, they steep it as we have described above. Afterwards it is washed, and spread out upon the ground to bleach. It must be remarked that, after every dipping, the cloth is washed first with black soap, then with clear water, and, after each of these operations, is wrung by means of a machine that turns with a wheel."

It will not much interrupt this narrative to remark, that at this period, no one attempted to explain the operation of the atmosphere in bleaching. Many years afterwards, Mons. Berthollet, in order to be able to account for the effect of crofting linen and cotton goods, examined the dew which falls from the atmosphere, and also that which transpires from the grass, and found both to contain a sufficient portion of oxygen to destroy the colour of turnsol paper [30].

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[29] For coarse linens it was usual to employ sours made by the fermentation of bran and water, instead of butter-milk. This was prepared in different ways, as may be seen in Dr. Home's work, p. 34.

[30] *Annales de Chimie*, tome ii. p. 158

"The whitening grounds are cut with canals in sundry places, that there may be no trouble of fetching water from a distance. The cloth is watered with long narrow shovels made in the shape of a scythe. The water of these canals comes from the downs, and it is that which contributes most to the lustre of the Dutch cloth. To prevent the water from becoming thick and muddy, they are extremely careful in cleaning their canals. The washing tubs are built in with bricks, with two trap doors, or sluices, for admitting or excluding the water, according as it is necessary[31].

"The greatest part of the Dutch cloth is made of Silesia thread, and the linen wrought at Haarlem and Almelo is infinitely superior to that of all the other manufactories. But the greatest part of that which is bleached at Haarlem, is cloth from Silesia and Overyssell; where flax grows in great abundance. All these foreign cloths, after being softened, whitened, and having obtained a gloss, at Haarlem, are transported to different parts of the world, and sold under the appellation of Dutch cloths, or Hollands."

Such was the process in Holland[32] sixty or seventy years ago, when few persons, comparatively, had, in this country, turned their attention to the

[31] In hot seasons this practice is very efficacious. In the East Indies, linens and cottons are at this day bleached by mere exposure on the grass, accompanied with frequent watering.

[32] An account of a Dutch process somewhat different from this, may be seen in Dr. Home's work, p. 23.

subject. From a circumstance which accidentally came to my knowledge, I have reason to think that the Irish acquired the art of bleaching after the Dutch method, long before either the Scotch or the English. The superiority of the Dutch linens, however, at length awakened a laudable emulation among the British manufacturers, especially the Scotch, who for several years much excelled the English in the process of bleaching all kinds of goods made with hemp or flax, although they had formerly been in the practice, and even so lately as the year 1752, of sending all the linens which had been made in their country over to Haarlem to be bleached.

To send so heavy an article to Holland, to be returned again to this country, was a tax upon the British munufacturer, which was not likely to be long endured, especially as all the goods which had been manufactured the preceding year were usually sent over in the month of March, and were never returned to Scotland, in a finished state, until the month of October; and then it was necessary to send them to London to be sold, where they were disposed of under the denomination of SCOTCH HOLLANDS.

Other instances might be adduced in abundance, to show the inconveniences which the manufacturers of this country endured in the middle of the last century, from a want of that chemical knowledge which any man may now easily acquire. At present one circumstance occurs to me, which is

connected with our subject, and may deserve to be mentioned.

In the year 1749, an Irishman, who had learnt something of the nature and art of bleaching, settled in the north of Scotland, and established a work there for the purpose of bleaching Scotch goods. This individual applied to some of the most eminent of the Scotch manufacturers, who were so pleased with the prospect of being able to bleach at home, that they readily intrusted him with goods to bleach. These, however, were so ineffectually managed, that their owners were compelled to send them over to Holland to be cleared and finished. The next parcel which these proprietors furnished him with, were bleached no better; for, after having kept them in operation the whole of that summer, and half of the next, the goods were returned very much injured, and even rendered tender by the process. In the course of a few years, however, this same person became an excellent practical bleacher; all the neighbouring manufacturers employed him, and from that period no more goods were sent to Holland. The consequences of this were two-fold: the Scotch manufacturers were much benefited; and this persevering individual acquired great opulence from the profits of the business which he had established. For the detail of these circumstances I am indebted to a gentleman of science, an indefatigable Member of the British Parliament, who collected them from the manuscripts of his father,

who was an eminent linen manufacturer in the north of Scotland.

It would occupy too much room in these pages to describe separately each of the processes that were formerly adopted in these kingdoms for bleaching; but, as that of flax yarn was one of the most important, I have thought it worth while to relate how this was conducted, under an idea that such a detail will prove interesting to the young bleacher, who has yet had no opportunity of witnessing any operation but that which is effected by chlorine gas, or the salts which are formed by its means.

In several parts of these Islands the preparation of flaxen yarn for the manufacture of various kinds of goods, is a business of very considerable consequence; it is (or at least has been) one of the staple trades of the country.

A pound of linen yarn cannot be bleached at less than four times the expense of bleaching a pound of cotton yarn. The reason is, that the quantity of colouring and resinous matter to be abstracted from the one is much greater than from the other. The thread made with flax will lose 27 per cent. of its original weight before it becomes perfectly bleached; whereas cotton yarn will lose only 4½ or 5 per cent. by a similar operation. The following was the process usually adopted for bleaching flaxen yarn.

The first operation, that of *steeping*, is extremely

simple. It consists merely in immersing the brown yarn in hot water, or otherwise allowing it to macerate cold in waste alkaline lyes. When pure water only was used, the goods were generally kept in it for three or four days, whereas with cold alkaline waste lyes forty-eight hours were usually deemed sufficient.

The intention of steeping was to occasion a kind of vegetable fermentation, which loosened the saliva employed in spinning the yarn, and so far separated the other impurities attached to it, that the whole were afterwards easily removed by washing in river or spring water, and which, in large concerns, was usually performed by machinery.

The next operation was that of boiling in an alkaline lye, or *bucking*, after which the skeins were exposed on the grass for two or three weeks, and then boiled or bucked a second time, again well washed, and then crofted as before. *Bucking* is a technical term for boiling, or steeping, in hot alkaline lyes, in an apparatus which is so contrived that the lye flows alternately over the goods and into a heated copper*. From this a pump, which is usually worked by steam, throws it again on the goods, through which it percolates till it reaches the bottom of the vessel, when, by the removal of a plug, it is run off again into the boiler, where it becomes again heated, and from whence it is pumped up as before, and the process goes on uninterruptedly

* A drawing of this apparatus will be seen in Plate No. XXI.

for many hours. According to Dr. Home, clear sunshine, with a very little wind, is the best weather for bleaching[33]. Crofting is a technical phrase for the act of exposing linen or cotton goods on the grass. These alternate operations of bucking, washing, and crofting, were generally repeated four or five times, each time lessening the strength of the alkaline lixivium in which the bucking was performed.

The next process was that of *souring*, which consisted in soaking the yarn in milk which had become acidulous by age, and which was usually employed for the first time immediately after the fourth or the fifth repetition of the bucking or the boiling operation. In this liquor, which was technically called the *first sour*, the goods generally lay for two or three weeks, or until such time as the scum began to crack and subside, when they were usually taken out and submitted to a repetition of the several operations already described.

Thus, whenever the goods had been once soured, the operations of bucking, washing, souring, and crofting, were repeated in regular rotation, until the yarn came to a good colour, and was esteemed perfectly clean. And it should be remarked, that these alternate applications of the alkali and the acid, in this mode of bleaching, were absolutely necessary to give the oxygen of the atmosphere an opportunity of acting upon the colouring matter, and preparing it for the next operation. In these

[33] Home *on Bleaching*, page 70.

operations the alkali probably carbonizes the colouring matter, or puts it in a suitable state for the oxygen to convert it into carbonic acid, or into a gaseous substance, easily carried away by the wind, viz. carbonic acid gas. For if any portion of the alkali was left in the goods when they were laid on the meadow, it would not only prevent the whitening process from going on properly, but would impair the strength of the article, and in like manner, though in a less degree, the goods would be injured by the remaining acid; but by the contrivance of using the acid and the alkali alternately, each of them becomes neutralized, the resulting salt has no injurious action on the fabric, and yet it is in a state for being easily removed by washing in pure water. In these latter operations a portion of soap was always employed, it having been found that this had the effect of making the goods handle better, and also of cleansing them more effectually.

This method of bleaching was extremely tedious, so much so, that if the first operation was begun in the month of March, the goods were seldom finished before September; and such as were laid on the grass for the first time at Midsummer, were only about half bleached that year, and were laid by to be finished in the spring of the following year. The probable reason why the proprietors of bleaching grounds took no measures to prevent this interruption of the process was, because they had found by

experience that the atmosphere during the months of March, April, and May[34], acted more efficaciously in whitening the goods.

About the middle of the last century, these tedious operations were much shortened, by the employment of sulphuric acid, instead of sour milk; an improvement first suggested by Dr. Home, in consequence of the new and important process, adopted about that time by Dr. Roebuck, for manufacturing sulphuric acid, which reduced that acid to one-fourth of its original price[35].

The public was, however, much alarmed by the introduction of this acid, on account of its corrosive nature, till Dr. Home published a volume on bleaching, in which he stated how much the sulphuric acid is always diluted for this purpose, and that "he had kept linen in a strong sour of oil of vitriol for many months, and that the cloth was as strong after it was taken out as when it was put in[36]."

No sooner was this new agent employed in bleaching, than it was discovered that one souring with sulphuric acid might be finished in 12, 18, or, at most, in 24 hours; whereas every souring by the milk process required from two to six weeks,

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[34] In bleaching, the ancients always gave a preference to the dews which fall in the month of May. See *Mémoire de Blanchiment des Toiles*, &c. *Annales de Chimie*, tome ii. p. 159.

[35] See Essay VII. vol. i. page 476.

[36] Home *on Bleaching*, p. 88.

according to the state of the weather and other adventitious circumstances. Besides, sours of this description hasten very fast to corruption. Indeed, as the milk is generally kept very long, it is often corrupted before it is used, and then, without acting as an acid, it has all the bad effects of putrefaction in injuring the fibre and weakening the cloth; whereas the sours made with sulphuric acid are not liable to putrefaction.

Berthollet says that he made comparative experiments on the effects of sour milk and sulphuric acid, and found the latter not only to be more efficacious, but to produce a better white[37]. The mere introduction of sulphuric acid occasioned such an improvement in the art of bleaching, that the whole process might then have been easily finished in four months, though it had formerly required seven or eight months for its completion.

The most important discovery, however, in this business is that of the oxy-muriatic acid (or chlorine), and its application in whitening goods made either of linen or cotton. The introduction of this article forms absolutely a new era in the history of this art; for it not only expedites the process surprisingly, but has become the means of reducing the practice of bleaching to a perfect science.

For this most important discovery we are indebted to Scheele, who in the year 1774 first formed chlorine by art, and afterwards ascertained

[37] *Annales de Chimie*, tome ii. p. 159.

its power in destroying vegetable colours[38]; although it appears that at first he investigated its nature more as a matter of curiosity than of use.

Several years seem to have elapsed before any one thought of applying the peculiar properties of this singular gas to any important purpose; and I presume it was not suspected that this powerful agent might be employed in any considerable process of bleaching linen or cotton until about the year 1784.

The first person who made experiments upon this gas, with a view to its successful application in the arts, was M. Berthollet, the French chemist, who in the *Journal de Physique* for June 1785, and again in the number for August 1786, explained the nature of its action on vegetable colours, and suggested how it might be employed with advantage in any of the existing establishments.

In the year 1787, the Academy of Montpellier transmitted to Chaptal several observations on chlorine, in order to their being printed in the National Memoirs for that year; and a report on the subject of this communication was immediately presented to the Royal Academy of Sciences. This report, which contains many very interesting particulars, was afterwards given to the world in the *Annales de Chimie*[39].

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[38] See *The Chemical Essays of Charles William Scheele*, translated by Beddoes, from the *Transactions of the Academy of Sciences at Stockholm*, p. 90.

[39] *Annales de Chimie*, tome i. p. 69.

In the early part of the year 1787, Mr. Copland, Professor of Natural Philosophy in Marischal College, Aberdeen, was accompanying the present Duke of Gordon in his travels on the Continent, and they passed some weeks at Geneva, with Professor de Saussure, under whose direction His Grace had studied in the early part of his life; and he showed these travellers the experiment, which they had already heard of, but had never before seen, of discharging vegetable colours by means of chlorine gas.

Impressed with the idea of the importance of this discovery to our manufactures, Professor Copland, on his return home, communicated all the circumstances, and displayed the properties of the new gas, to some particular friends of mine, eminent manufacturers in that neighbourhood, who immediately entered upon a course of experiments for the preparation of chlorine, with a Woolfe's apparatus, and obtained a very satisfactory result.

This was about the end of July, in the year 1787, and from that time these gentlemen continued to apply this mode of bleaching in their manufactory, especially for finishing such orders as were limited in point of time. But, in applying this discovery to actual practice on a large scale, they very soon perceived that the circumstance of the gas being prepared in an apparatus of glass, would be a serious obstacle to its general adoption; and therefore, when they came to extend its application to larger

quantities, they made use of vessels of white wood instead of glass.

The gentlemen of whom I now speak, and to whom Professor Copland communicated the information he had obtained, were Messrs. Milnes, of the house of Gordon, Barron, and Co., of Aberdeen; and I have reason to believe, that theirs was the first actual application of chlorine to the purpose of bleaching either linen or cotton goods for sale in Great Britain.

In the early stage of the business, the chlorine gas was procured by the distillation of the common muriatic acid, from the black oxide of manganese; the direction which Scheele had given for this purpose being to mix 4 pounds of the acid with 4 pounds of water, and then to distill this mixture in a well luted apparatus, from one pound of the black oxide of manganese, and to collect the gas in a large receiver of cold water.

The last survivor of the Milnes above mentioned, was the late Patrick Milne, Esq. several years representative in Parliament for the borough of Cullen. It was this gentleman who first informed me of the circumstances just related, and to him I was indebted for several important facts contained in this Essay.

Fearful, however, lest, in consequence of lapse of time, my friend might have forgotten or mistaken some circumstance, I took the precaution of writing to Professor Copland, who replied, that he

perfectly recollected, and acquiesced in all the particulars of my statement. In addition to this testimony His Grace the Duke of Gordon, with the utmost affability and condescension, has suggested, that, as it may add to the authenticity of the account, I am at perfect liberty to make use also of his name, either in my publication or in any other way in connexion with this subject.

At the time of which I have been speaking, M. Berthollet had been engaged for twelve months in investigating the nature of chlorine gas for the purpose of ascertaining the best and most economical methods of applying it in whitening cotton and linen cloth. Just then, Mr. James Watt, of the Soho, Birmingham, happening to be at Paris, M. Berthollet invited that eminent man to witness his experiments; and it appears that he communicated to him, without reserve, the full amount of the discoveries which he had made in the new process of bleaching. From some documents which have been printed on this subject, it would seem that this unreserved intercourse between these two great men, was kept up for a considerable time, or at least until Mr. Watt had made himself acquainted with the whole of the favourable results, as well as the repeated difficulties which M. Berthollet had experienced in the prosecution of this business.

On the return of Mr. Watt to Great Britain, he appears to have lost no time in communicating the whole of the information he had obtained, to his

relative Mr. MacGregor, a large bleacher at Glasgow; for, in his subsequent correspondence with M. Berthollet, he informed him, that he had applied his discovery to real practice, and in his first attempt had bleached five hundred pieces of cloth by the new method. He adds that Mr. Mac Gregor was so highly satisfied with the result, that he had determined to continue the process.

Abundant evidence, indeed, might be obtained from Scotland, to show that Mr. Watt did not relax in his endeavours until he had established the new process in Mr. MacGregor's bleach-field on a permanent basis. We have seen that he continued a correspondence with Berthollet for a considerable time on the subject; and Dr. Henry assures me, that he has in his possession a number of letters which passed between his father, Mr. Thomas Henry, and Mr. Watt, in the year 1788, on the business in which they were both so zealously engaged. In one of these letters, which bears the date of the 23d of February 1788, Mr. Watt informs Mr. Henry, that at that very time 1500 yards of linen were bleaching by the new process under his direction; and desires that this circumstance may be stated to a meeting of the manufacturers and merchants of Manchester, then called by public advertisement, for a purpose to be hereafter mentioned.

I have been more circumstantial in these details, because I had been charged with having too slightly passed over the exertions which were made by Mr.

Watt to introduce the bleaching by chlorine into Great Britain. For, however the question may stand respecting the claims of priority, I was fully aware at the time when the first edition of these Essays was published, of the obligations the country was under to that gentleman upon this particular business, as will appear from the following passage:—

"I have no doubt", said I, "that Mr. Watt was the first person in Great Britain who introduced science into the bleaching process; for, before his connexion with Mr. MacGregor, whose daughter he had married, the whole operation of bleaching was merely the effect of observation and practice. In justice to Mr. Watt, it must also be remarked, that Mr. MacGregor's work was much improved by the former gentleman, long before he became acquainted with Berthollet, and several years before he witnessed his experiments with oxy-muriatic acid[40]."

When these circumstances are all considered, it may be difficult, at this distance of time, to determine whether chlorine gas was first employed in the bleach-field of Mr. MacGregor at Glasgow, or in the works belonging to Messrs. Milnes at Aberdeen; or, in other words, whether Professor Copland or Mr. Watt is entitled to the credit of having first introduced gas bleaching into some of the then existing establishments of Scotland. Be

[40] See the first edition of these Essays, vol. iv. page 55.

this, however, as it may, it is pretty clear that both these gentlemen were zealously engaged in the same undertaking about the same period, and that the process was fully established at Aberdeen and at Glasgow long before it was employed in any other part of Great Britain.

But to pursue the account: In the year 1788, the attention of several persons at Manchester, particularly that of Mr. Thomas Henry [41], was directed to the subject, and an experimental examination of the nature of the new bleaching agent was entered upon by several individuals who had usually been engaged in different pursuits, but who were all stimulated by the hope of obtaining either private or public advantage from the result of their investigations. Just now, however, an unexpected circumstance occurred, which was thought likely to be very injurious to the town and trade of Manchester, and this had the effect of uniting the efforts of those persons in that town and neighbourhood, who had been endeavouring to acquire a knowledge of the new process of bleaching by means of chlorine gas. MM. Bourbollon de Bonnueil and Co. French Chemists, had applied to the English Parliament for an exclusive right to the invention of a liquid for whitening linen and cotton in a shorter time than by the old method; and this

[41] The person here referred to is the late Thomas Henry, Esq. F.R.S. President of the Literary and Philosophical Society of Manchester; and author of several works on a variety of interesting subjects.

so alarmed the printers and bleachers of Manchester, that a meeting of the manufacturers and merchants of the town was called by public advertisement for the express purpose of considering the plans and the petition of the said foreigners.

At this meeting half a piece of calico was produced which had been bleached immediately before, by Messrs. Cooper, Baker and Taylor, by the new method; and at the same meeting Mr. Thomas Henry produced, not indeed half a piece, but half a yard of calico, which he had just bleached by chlorine gas. What was wanting, however, in quantity, was made up by the quality of the work; and the smaller specimen was declared to be superior in whiteness to the larger one.

The result of the public meeting was, that in consequence of the specimens of bleached calico which had been produced, and of the facts stated by Mr. Henry, and Mr. Thomas Cooper, who was also a man eminent for scientific attainments, and of a letter from Mr. Watt to Mr. Henry, which was read to the meeting, stating that he had at that very time 1500 yards of linen bleaching by the new process under his direction, the members for the county were instructed to oppose the petition above mentioned, when presented to Parliament. The consequence of this was, that the petition was refused; and afterwards, when the same people made application for a patent to secure to themselves the sole right of selling a bleaching liquid, Mr.

Henry drew up a Memorial, which was presented to the attorney-general against the claim of the petitioners, and which contributed in a considerable degree to their want of success. This document is dated July 2d 1788, and contains an account of the processes then actually practised by Mr. Henry, and comprehends every thing at this day known respecting the use of chlorine gas in bleaching, with the exception of the application of lime to the condensation of the gas. This document, which is still preserved, places beyond all controversy Mr. Henry's right to rank among the first improvers of the process of bleaching.

I was not aware of these facts when the former edition of these Essays was published, or I would not have withheld them from that public which is indebted to Mr. Henry for many patriotic and benevolent exertions during the course of a long, useful and honourable life[42].

That I might give a faithful detail of these particulars, I have availed myself of the account published by his son, Dr. William Henry, in one of the early volumes of Dr. Thomson's Annals of Philosophy[43].

Soon after the Manchester meeting of which I have spoken, Mr. Charles Taylor, a calico-printer

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[42] For some account of the various writings of the late Mr. Thomas Henry, see "A Tribute to his Memory," published in the 3d vol. Second Series of the *Memoirs of the Literary and Philosophical Society of Manchester*, page 204—240.

[43] See Thomson's *Annals*, vol. vi. page 421—424.

of Manchester[44], in conjunction with Mr. Thomas Cooper, also of Manchester[45], bleached a whole piece of cotton by the new process, and printed and calendered it fit for the market in less than three days. The success of this experiment was so decisive and unexceptionable, that Mr. Cooper and some other neighbouring gentlemen were induced to establish at Raikes, near Bolton, in Lancashire, a bleaching concern of very considerable magnitude, to be dependent entirely upon the agency of chlorine gas.

Little doubt could now be entertained that the new process would eventually be brought into general use: and it will be seen hereafter that it soon found its way into other parts of Great Britain besides Aberdeen, Glasgow, and Manchester.

I have already adverted to the circumstance of M. Berthollet being the first scientific chemist who directed his attention to an inquiry into the uses of chlorine gas in the arts; and have also observed that he gave several memoirs on the subject to the Academy of Sciences, all of which are preserved in their collections for the year 1785.

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[44] This gentleman, was afterwards elected Secretary to the Society instituted in London for the Encouragement of Arts, Manufactures and Commerce.

[45] This gentleman who removed to America, and was appointed one of the Judges of the United States, has lately published a short Memoir on Bleaching, in the "*Transactions of the American Philosophical Society*, with drawings of an apparatus suitable for the use of private families. See vol. i. New Series, quarto, page 317. Dr. Thomas Cooper is now the President of Columbia College, in South Carolina.

In the year 1789, which was one year after those favourable specimens of the facilities of the new method of bleaching had been exhibited in Manchester, as mentioned above, M. Berthollet brought the subject again before the public in a masterly memoir, entitled "*Du Blanchiment des Toiles et des Fils par l'Acide muriatique oxigéné, et de quelques autres Propriétés de cette Liqueur relatives aux Arts.*" In this memoir he gave a very circumstantial account of the system of bleaching by the new method, with ample directions to the manufacturers respecting the construction of an improved apparatus for the purpose of preparing the bleaching liquid[46].

From this memoir it appears, that gas-bleaching was now adopted in various parts of France[47], and that the chief obstacle to its being brought into general use was the want of a convenient and safe apparatus for the production of the chlorine gas: though, besides the inconvenience of forming the gas, great objections were continually made to the noxious nature of the fumes, which very much annoyed the workmen. In what manner this latter difficulty was surmounted will be seen in the sequel. The great desideratum was however accomplished by Berthollet, and it formed the main object

[46] See *Annales de Chimie*, tome ii. p. 151—190, and tome vi. p. 204.

[47] A very particular account of the methods of bleaching in Picardy, and also at Anjou, is given by Mr. Nicholson in his 8vo *Chemical Dictionary*, article *Bleaching*.

of his memoir to explain very minutely the construction and principle of the apparatus he had contrived, together with the proportion of the materials for distillation, so as to render the practice of chemical bleaching general and efficacious. His directions are, to use

6 ounces of pulverized oxide of manganese,
1 lb. of sea salt,
12 ounces of sulphuric acid, and
12 ounces of water.

A folio plate, accurately engraved, accompanies the volume, with letters of reference, and such an ample description that nothing can be mistaken.

Other writers advise proportions different from those above given. Thus, Mr. Rupp directs 3 parts of manganese, 8 of salt, 6 of oil of vitriol, and 12 of water[48]; whereas Tennant advises equal parts of the three former, and water equal to the oil of vitriol, by *measure*, as noticed at p. 293. In France, the usual proportions are these: 3 parts of manganese, 10 of the salt, 7 of the sulphuric acid, and 9 parts of water. But Sir Humphry Davy says, perhaps on the authority of Mr. Duffy of Dublin, that "the best proportions are 3 parts of common salt in weight, 1 part of manganese finely powdered, and 2 parts of oil of vitriol." He has, however, given no directions as to the quantity of water with which the sulphuric acid ought to be diluted; which is an important consideration.

[48] See *Manchester Memoirs*, vol. v. p. 301.

The memoir by Berthollet, before mentioned, contains so many interesting particulars respecting the progress of the new art, that it would be impossible for me to do justice to the subject which I have undertaken to elucidate, without repeating some of the circumstances related by this very acute writer.

At first he was perplexed by the discovery that the cloth was injured by the process; but in subsequent experiments he found that, when the liquor was considerably diluted, he was enabled to bleach without impairing the strength of the fabric. Another difficulty he had, which arose from the cloth sometimes becoming yellow after an interval of a few weeks, and this occasioned him much trouble. However, when he began to try the alternate action of the chlorine gas and alkaline lyes, he discovered that he was able to procure a perfect and permanent white[49]. I doubt not that Berthollet speaks here of his success in bleaching cotton, because the process which he describes always leaves a yellowness on linen goods, which can only be removed by a few days exposure on the grass.

In the mean time, while M. Berthollet was engaged in these experiments, a Mr. Bonjour, who had been an assistant to Berthollet in his first attempts, connected himself with a Mr. Constant, a cloth finisher at Valenciennes, for the purpose of forming a bleaching establishment at that town;

[49] *Annales de Chimie*, tome ii. pp. 158, 159.

but, owing to the violent opposition of the neighbouring bleachers, they were unable to procure ground for the purpose on any reasonable terms.

In this difficulty, a patriotic French nobleman, the Count de Bellaing, who favoured the enterprise, and was made acquainted with the extent of the opposition, gave them possession of a piece of land at some distance from the town, which had all the necessary conveniencies for the business. Here a large establishment was formed in the course of the year 1788; but notwithstanding the support which the proprietors had thus received, the opposition of the old bleachers, and the inveterate prejudices of the neighbourhood, were so great, that Mons. Bonjour was under the necessity of addressing the National Bureau of Commerce on the occasion. The chief prejudice arose from the circumstance of the new proprietors intending to substitute *chemical* bleaching for the old process of ashing and crofting.

Soon after this period, some manufacturers at Javelle, near Paris, announced in several journals, that they had discovered a particular liquor, which they called the *Lye of Javelle*, having the property of bleaching cloth by a few hours immersion. This composition, which was immediately analysed by Berthollet, was found to be nothing more than a solution of the oxy-muriate of potash; and, on his attempting to prepare the solution, he immediately perceived that the addition of the potash to the water caused it to imbibe the gas sooner, and

that it likewise formed a more concentrated liquor. This was similar to the liquid which is now sold in London in small bottles, under the name of bleaching liquid, for the use of private families. A convenient article for this purpose may be prepared by receiving the gas which arises from the distillation of 3 pounds of common salt and 1 pound of manganese, into a receiver containing 1 pound of best American pearl-ash dissolved in 4 pounds of water. Two pounds of sulphuric acid previously diluted with 4 pounds of water, will be sufficient for extricating the gases from the materials above mentioned.

At the time when Berthollet published the memoir from which I have taken some of the foregoing particulars, few persons in England were acquainted with any mode of bleaching by means of chlorine, except when in the state of gas; and in this way many attempts were made, in various places, by some of the best informed and most practical men in their respective districts.

At Nottingham, some considerable manufacturers succeeded tolerably well in bleaching small parcels of linen-yarn, linen, and cotton hose, and other small goods, which they effected in the following manner: The articles having been suspended within large wooden boxes, each of which had a close bottom capable of holding water [50], the gas

[50] An excellent apparatus for gas bleaching was invented by Mr. Rupp. A description of it may be seen in the 5th vol. of the *Memoirs of the Manchester Philosophical Society*, page 298—313.

was conveyed into these receptacles; and, to prevent any injury by the immediate application of the gas, the goods were, by means of a frame and pulley, let down occasionally, and indeed frequently, into the water beneath. But by this method there was great difficulty in exposing all the surfaces of the goods equally, without which no perfect bleaching can ever be effected.

This practice was continued, however, with considerable advantage, though not without its inconveniencies, until the manufacturers of Javelle, before mentioned, having been disappointed in their commercial prospects at home, came over to England, and settled at Liverpool, for the purpose of manufacturing the solution of oxy-muriate of potash, which they proposed to sell to the English bleachers in bottles, and which they still denominated the *Liquor de Javelle*.

These men, although they had been unable to introduce their article in France, so that it might have been consumed in sufficient quantities to answer their purpose, were so sanguine respecting the sale of it in England, that they applied to the British Parliament for an exclusive right to the invention, for the term of 28 years, as before mentioned. Fortunately, however, one of the gentlemen who first applied the oxy-muriatic acid to the purposes of bleaching in this country, as mentioned at page 277, happening to be in the gallery of the House of Commons at the time the application was

made in behalf of these foreigners, he took immediate measures to inform the principal members that this was not a new process; that he himself had long ago prepared an article equally efficacious, and that he would be ready to substantiate the truth of his statement when required. This representation, together with the petition from the town of Manchester, had the desired effect—the purpose of these Frenchmen was defeated, and the act which they had petitioned for, was not obtained.

Notwithstanding this disappointment, these gentlemen continued to carry on their work at Liverpool for a considerable time: but, from the article being bulky, and from its constant loss of strength by the action of light, or by exposure to the air, the obstacles to its consumption continued to augment, until in the end they were obliged to relinquish the establishment altogether.

After this, a Mr. Foy, who had been one of their operators at Liverpool, waited upon some of the principal manufacturers, and proposed, for a considerable premium, to erect for them the necessary apparatus, and to instruct them in the process of making the Liquor de Javelle at their respective works.

This proposal was acceded to by many, and the oxy-muriate of potash was for some time generally employed. The combination of potash with the chlorine has the effect, however, of weakening its bleaching power; but this is more than compen-

sated by the circumstance of this compound being less obnoxious to the workmen than the oxy-muriatic acid alone.

In the year 1798, Mr. Tennant, of Glasgow, took out a patent for a new bleaching liquor, which was a solution of chloride of lime instead of that of oxy-muriate of potash, and which he engaged to sell much cheaper than the article that had been prepared by the foreigners; but as this was also sold in a liquid state, one of the main objections to the Liquor de Javelle still remained.

In order, however, to remove this objection, Mr. Tennant undertook to convey to several manufacturers for the sum of 200*l.* to be paid by each, a right to work under his patent; and this proposal having been accepted by many of the principal manufacturers, this method of chemical bleaching was soon very generally adopted throughout the kingdom.

The drawback of the duty on salt, which since this period has been granted by Parliament to all those who make these preparations for their own use, has induced not only the bleachers, but also some of the large calico-printers, to make their own bleaching liquors, especially since the legal determination respecting the validity of Mr. Tennant's patent; so that an apparatus for this purpose is now considered to be a necessary adjunct to most of the printing establishments in the north of England.

The following is Mr. Tennant's process: In a re-

ceiver containing 140 gallons of water (wine measure) he dissolved 30 pounds of common salt, for the purpose of giving greater specific gravity to the water: the salt being dissolved, he then added 60 pounds of quick lime in an impalpable powder. In charging the retort for the production of the gas, 30 pounds of powdered manganese were mixed with an equal weight of common salt, and to this mixture were introduced 30 pounds of sulphuric acid, previously diluted with 18 pounds of water. These are the proportions which were originally given by Mr. Tennant in the specification of his patent. He directed that the contents of the receiver should be agitated constantly during the whole of the distillation.

Some time after Mr. Tennant had made these arrangements with several of the manufacturers, some spirited individuals undertook to impugn the validity of his patent; the consequence of which was, that on the question being submitted to a legal decision, the cause went in favour of the public, and the right of patent was lost.

Since this determination, which gave great satisfaction to the whole body of manufacturers, there has been no impediment to the method of bleaching by chlorine gas; and this chemical agent was for some time prepared at most of the great works by the proprietors themselves, and according to the process above mentioned, with perhaps some trifling variations.

In the year 1798, the same year in which Mr. Ten-

ment introduced the process of combining the chlorine gas with lime, an Act was passed "to allow the drawback of the whole of the duties then payable upon all salt of English manufacture which should be used and consumed in making the oxymuriatic acid, provided such salt should be mixed with the other materials, in the presence of an officer of Excise, and in the proportions of at least 20 pounds weight of sulphuric acid, 20 pounds weight of manganese, and 10 pounds weight of water, to every 56 pounds weight of salt[81]. This boon, which is really very important to the national interests, was thankfully received by the manufacturers and bleachers, and all the large proprietors immediately availed themselves of it.

The peculiar advantages of combining the chlorine gas with lime or potash, consists in this circumstance, that the saline solution gives out the gas gradually to the goods which require bleaching, but does not give it out with facility to the atmosphere. In consequence of this, the operation of bleaching is now not injurious, nor even very disagreeable, to the workmen; whereas in the former process, when the gas was merely received into water, it was given out again so freely, that no man could long endure to work in it, or even for any considerable time to superintend the operation.

The preparation of chlorine, and the manufac-

[81] See the 38th Geo. III. cap. 89, § 89, p. 855.

ture of bleaching powder, are always disagreeable and dangerous operations, and ought not to be undertaken by any but experienced men. That eminent French chemist, M. Pelletier, lost his life by inhaling a large quantity of chlorine gas; and I have lately been informed of another instance of the fatal effects of this potent agent, which occurred very soon after its discovery by Scheele. Mr. Roe, of Ringsend near Dublin, a young man eager in the pursuit of chemical knowledge, died after a very short illness, in consequence of his inspiring this gas too freely, while engaged in making experiments to investigate its nature and properties.

In resuming the account of the process of bleaching it may be observed, that, in addition to the foregoing advantages, resulting from the combination of lime with the chlorine, the saving in interest of capital is incalculable, as will appear from one or two considerations.

In bleaching *linen* goods, in a great work, where one large parcel follows another, in regular succession, and through the different operations, five weeks is as much as is now ever allowed for their completion, and a small parcel can be begun and finished in a few days; whereas, by the old process, the effect could never be fully produced in less than eight months, as I have before mentioned. Now, a country person who weaves only a single piece of cloth, may bleach it himself, and have it immediately ready for market. Indeed, were these poor weavers properly instructed, it would be of great

service to the manufacturing interests of the nation. The introduction of chlorine has also taught the scientific bleacher to understand the nature of his materials, and the proper use of them. Thus, the economical workman of the present day brings all his alkaline lixiviums to the most caustic state, and then reduces them by water to the proper degree of strength for his respective operations. I have the pleasure of being acquainted with the proprietors of a large bleach-field, who have told me, that they formerly used 12 cwt. of Dantzic weed ashes to bleach a ton and a half of linen yarn; but that since they have learnt how to ascertain the goodness of the material by chemical analysis, they are enabled to finish the same quantity of yarn with 2 cwt. of caustic American potash, which costs them not more than one fourth of their original expenditure. Here is a manifest proof of the incalculable value of chemical knowledge to a manufacturer. The solution of chloride of lime the economical bleacher treats also in the same way, and ascertains its strength not merely by the hydrometer proof, but by the real degree of power which it has of discharging vegetable colours. The difference between the *hydrometer* strength and the *discharge* strength is very important; because, if the former only be attended to, the liquor may be so strong of muriate of lime as to have a proper specific gravity and yet have a very weak effect in bleaching; whereas, if the article be made up merely by its discharging strength, or its power of depriving a

solution of indigo of its colour, it may be right in this respect, and yet contain so much muriate of lime as would be injurious to the goods bleached by it. Sir H. Davy for the purpose of experiment boiled some linen in a strong solution of muriate of lime, and found the fabric of the cloth much impaired by the process.

Moreover, the bleaching of linen yarn was formerly very seldom accomplished with less than from 33 to 35 per cent. of waste, whereas the waste now is not more than 26 or 27 per cent. This, of itself, is a presumptive proof that the goods are less injured, and evinces the superiority of the present practice. Berthollet has very properly remarked, that "by the old method the small bleacher was always obliged to sell his cloth to a disadvantage; the large manufacturer had his capital locked up for a longer time than is now necessary; and the consumer had not so good or so strong cloth as he may now have by the new process. The bringing back into agriculture the vast quantity of land formerly employed for bleaching, and this at the finest season of the year," he adds, "is likewise no small advantage [52]."

The difference in the quantity of the waste by the two processes arises from a circumstance that is not much known, but which alone ought to be sufficient to remove the prejudice which is generally entertained against what is called chemical bleach-

[52] *Annales de Chimie*, tome ii. p. 184.

ing, viz. that the chlorine process when properly conducted removes only the resinous matter and other filth; whereas the long exposure on the grass, and the various and reiterated operations of the old method, waste also a part of the fibre itself, and consequently weaken the whole fabric.

This reminds me of another erroneous idea which is very prevalent and ought to be corrected, viz. that no kind of acid can be employed with effect in bleaching, without the cloth sustaining an injury.

I have heard of a dispute, which arose only a few years ago, between a confidential agent of the British Government and the principals of a large manufacturing establishment, who had a great quantity of white canvass refused because it was discovered that diluted sulphuric acid had been employed in bleaching it, after it had been stipulated that the process should be completed without acids. In forming this contract, the proprietors of the bleach-works had an eye only to the prohibition of what was then called the oxy-muriatic acid and its compounds, never having conceived an idea of bleaching without the employment of some kind of sours to remove the adhering alkali. What tended to confirm the prejudice was this, that an appeal had been made to an eminent chemist, who had declared that the use of acids in bleaching must always be injurious.

In opposition, however, to this authority, I have no hesitation in pronouncing that no good bleaching can ever be effected without acids. There would be

no safety in doing it, and it is what no experienced bleacher would ever attempt; because, were acids not to be employed to neutralize the alkali which had been used in the previous operation, the alkali which remained would not fail, when assisted by the sun's rays, to injure and in some measure destroy the cloth. This effect is so certain, that it will happen to the goods should they ever be laid on the grass only after one single operation without being soured. This sometimes occurs from the carelessness of the workmen; but whenever this happens in summer, it can always be detected by the master, as the colour of the goods will be deteriorated, and they will have become what the bleacher calls *lye-burnt*.

Now that I have ventured these remarks, the next step will be to give an account of some of the MODERN processes in bleaching, which I shall endeavour to do with as much brevity as is consistent with perspicuity. It will be most convenient to begin with the process of bleaching *linen* yarn and *linen* cloth.

In effecting this, the same methods are followed, as far as to the fourth or fifth bucking, as were formerly employed in bleaching linen long before the application of chlorine, and which have already been detailed at page 270—273; only good washing is resorted to instead of crofting. This being premised, the remaining operations may be described with less difficulty.

It may be asked, Why is not chlorine now employed in these first processes of bleaching linen goods? The reason is, because it would be too expensive; for there would be a greater expenditure of the chlorine gas in the removal of the filth and the resinous matter than is now incurred in the whole process, and these are all taken out in a much cheaper way by the solution of alkali and by repeated washings in pure water. The solution of chlorine is not necessary for the removal of the resin, but it is indispensable in discharging the colouring matter and the carbon.

It should be recollected, that no bleaching can ever be carried on to advantage, unless the water be pure and in great abundance. Hence Scotland seems to be peculiarly calculated for such establishments; for, as I have been informed, there are many parts of that kingdom which abound with spring water that comes from the granite rocks nearly in a state of absolute purity.

After the fourth or fifth bucking, the goods are immersed in a solution of chloride of lime, and are then well washed by machinery in pure water. They are now carried to the souring vessels containing a portion of very dilute sulphuric acid; and when taken out of these vessels, they are again well washed in water; and lastly, they are submitted once more to the alkaline process mentioned at page 271.

This kind of goods requires at least three immersions in the solution of chloride of lime, followed

by an equal number of alternate immersions in the sours and in the alkaline solution, carefully and thoroughly washing them in pure water between each of these processes. It should be remembered, however, that linens require generally a greater number of immersions in the bleaching liquor than cottons, and also that the preparation be less diluted with water.

By this method of bleaching, linen goods constantly acquire a yellowish tinge; this however is so superficial, that mere exposure to the air for a few days generally removes it. The goods are then finished by boiling them for a short time in a dilute solution of pearlash and white soap. This last operation has the effect of removing the disagreeable odour which otherwise would for a long time be attached to every article bleached by this process. It must here be remarked, that when *cotton* goods are bleached after this manner, there is no necessity for crofting; as the yellow tinge just mentioned does not appear in them when finished; any stain of that kind being completely removed by the sulphuric acid, though this acid will not remove it from linen goods[53].

We may also notice, that bleaching with chloride of lime will not answer for those cotton goods which are designed for the madder copper, because the sours, (diluted sulphuric acid,) however perfect the washing may be, will fix the earth within the

[53] See the account of Berthollet's experience in this particular at page 288.

pores of the cloth[54]; and although the lime thus fixed may be in a very minute quantity, indeed so minute as not to be detected in any other way, its effect will not fail to be seen when the goods have been passed through the decoction of madder. The sulphate of lime being a mordant for the madder, it will inevitably occasion a stain, and arrest the colour on those parts of the cloth which are designed to be preserved white.

Whenever this salt becomes fixed within the pores of the cloth designed for madder work, it will most certainly produce stains in the white ground which cannot be removed by crofting. I suspect this is an evil of more usual occurrence than many printers imagine; for I have seen the kiers, which are large wooden vessels used in bleaching, covered on their insides with sulphate of lime. This appearance shows that the workmen did not wash the goods completely when they came out of the sours. Some bleachers, indeed, designedly omit washing, because they imagine that the portion of the acid which adheres to the cloth is useful in giving activity to the chlorine.

I have likewise to notice another fault in this department of the business, viz. that of using pieces of sheet lead occasionally for lining or securing parts of the kier which are thought to be in danger of leaking. This is improper; because the sulphur, which is always contained more or less in potash, acts up-

[54] See an account of the Scotch mode of bleaching calicoes for the madder copper, in a subsequent part of this Essay.

on the lead, and gives it a red coat of sulphuret of lead, which will stain the goods coming in contact with it. I have also seen bowking-houses where the goods have sustained an injury from the iron nails used in the roof of the building; for where the roofs of such buildings are put together with nails, the steam from the boiling vessels will be condensed by the tiles, and the water resulting therefrom, washing off the oxide of iron from the corroded nails, will inevitably stain the white calico on which it falls. To construct a building in the best manner for bleaching, there ought to be no iron in the roof, nor any lime employed in the inner side of the walls, as the smallest quantity of lime or iron would materially injure those white calicoes which are designed for printing.

On these accounts, the large printers who bleach their own goods, frequently use oxy-muriate of potash or oxy-muriate of soda for all the cottons which are to be dyed with madder. This was recommended so long ago as the year 1789, by Mr. Thomas Henry of Manchester and M. Décroisille, and was afterwards communicated by Berthollet to M. Oberkamp, an eminent calico-printer at Jouy, as an agent for clearing the whites of maddered goods. M. Oberkamp immediately embraced the proposal, and continued the practice ever after [55]. It is a curious circumstance, that, although this plan of clearing the whites of printed goods originated in a great mea-

[55] See *Annales de Chimie*, tome ii. p. 187.

sure at Manchester, none of the English printers should have been aware of the importance of the practice till more than twenty years after its introduction at Jouy. To get rid of the selenite, or rather to prevent its being formed, attempts have been made to vary the process by following the dip in the solution of chlorine with an immediate immersion in the alkaline solution instead of the immersion in the sours; but this has always failed of success.

It is a common opinion, that the manufacturers give the preference to the new process of bleaching on account of its being cheaper, and because the materials for chemical bleaching cost less than those which were employed in the old method; but this is not the fact. Bleaching by the new process is as much dearer as is the amount of the cost of the solution of chloride of lime: but the great economy is in the saving of labour; in the certainty and security of the process; in the less degree of waste[66]; in the shortness of the time employed; and in the comparative smallness of the interest upon the capital engaged in the business.

There is a considerable trade now carried on in the bleaching of hose. The following is the process usually adopted, the accuracy of which may be relied on, as it was communicated to me some years ago by one of the partners in an extensive manufactory, who had come to London for the purpose

[66] For an explanation of this see page 298.

of consulting me respecting some difficulties which had occurred in their manufactory, and which at that time were attended with considerable loss and inconvenience.

Although it may be considered a digression, some persons may be glad to be informed that the stocking-loom was invented, about the year 1590, by the Rev. Wm. Lee of St. John's College Cambridge. This gentleman being desirous of bringing the machine into general use, and unable to procure any remuneration from the Government of his own country, he went over to Rouen in Normandy, where some spirited individuals undertook to introduce him to the French Minister, who gladly afforded him protection and patronage. He had previously applied to Queen Elizabeth; and it must appear not a little extraordinary that this monarch should have refused him her support, when it is recollected what patronage she afforded to Daniel Houghsetter and to many other foreigners, whom she had invited from different places on the continent of Europe to instruct her subjects in useful arts, and in the establishment of new manufactures.

In the establishments for the manufacture of cotton hose, the stockings are first scoured in soap and water, to divest them of the oil and other impurities applied in the process of weaving; because the weavers of cotton hose always dissolve mutton suet in melted soap, and pass the goods through the mixture. This serves a double purpose; it occasions the thread to work better, and renders the goods

heavier when they are returned in a finished state to the owner.

It is in consequence of this practice that the bleacher is under the necessity of scouring such goods in a solution of soap made scalding hot; for it would be in vain to attempt to bleach them without first divesting them of this tallow, and of the dust and other impurities which will unavoidably be attached to it. To obtain this the more effectually, they are removed from the scouring vessels into pure water and thoroughly washed, the water being changed as often as is considered necessary. Many inexperienced persons, who have begun the business of bleaching and also that of dyeing, have failed of success in consequence of their not being aware of the absolute necessity there is for observing the utmost cleanliness in both these occupations.

The second process consists in boiling the hose in a weak alkaline solution, made by dissolving three pounds of American pearlash in three hundred gallons of water. When boiled in this lixivium, they are merely rinsed in clear water, and are then considered to be sufficiently prepared for being submitted to the action of the bleaching liquor. The bleacher of piece goods would consider this to be a very weak lixivium, for in that process it is not an unusual thing to dissolve the above weight of caustic potash in so small a quantity as ten gallons of water.

The bleaching liquor for cotton hose is prepared by mixing six or eight quarts of the solution of chloride of lime, in the state in which it is prepared at

the still, with 20 gallons of water. In this mixture the hose are immersed, and they are suffered to remain an hour and a half or two hours. They are then taken out, and washed thoroughly in cold water.

The process of immersion in the bleaching liquid is now repeated, and this is followed by boiling the goods in an alkaline lixivium, as before. These processes of steeping in the chloride of lime and of boiling in a solution of alkali, are repeated four times alternately, and then the hose are generally found to be bleached sufficiently. The necessity there is for these repeated steepings in the solution of the chloride of lime, may be thus explained. The chlorine that is liberated decomposes a portion of the water, the oxygen of which combines with the colouring matter, and renders it soluble in the alkali.

These processes being finished, the goods are then immersed in diluted sulphuric acid, which has been so much lowered with water, that it is become little more acidulous than vinegar, and may be taken into the mouth with perfect safety. This carries off any earth or other matter not sufficiently soluble in the alkali. The steeping in this weak acidulous liquor is generally continued about three hours, though sometimes the hose are suffered to remain in it for a whole night.

It has been found, by repeated experiments, that so long as the goods are actually *immersed* in the sours, they sustain no injury; whereas, if they were

taken out and suffered to become dry, their texture would be much weakened, and the damage would be irreparable [57]. This, I have no doubt, is occasioned by the evaporation of the water, by which the sulphuric acid attached to the goods becomes concentrated and caustic.

To divest the hose of the remains of the sulphuric acid, they are washed many times in cold water, and even submitted to the action of a kind of fulling mill, called *fallers*, which cleanses these goods more effectually than could be done by any other method. But so difficult is it to remove the last portions of the sulphuric acid, that the manufacturers find it necessary, even after all this washing, to immerse them in a hot solution of soap and vegetable alkali, to finish their purification. The proportions are 4 pounds of white soap, 1 pound of best pearlash, and 150 gallons of water. This process is technically called *scalding*. This removes the disagreeable smell of the chlorine gas, at the same time that it improves the appearance of the goods to the eye, and occasions them to feel softer.

The hose are now carried again to the fallers; where they are scoured and beaten in soap and water, as before, the remains of which are perfectly washed out with successive portions of pure cold water. This is said to complete the process of bleaching.

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[57] See an account of Dr. Home's experiment on this subject, p. 274 of this Essay.

These goods are afterwards exposed to another process called *getting up*, which is performed in the following manner. They are put into a copper of hot water, containing a weak solution of soap, with the addition of a little indigo, sufficient to give them a tinge of blue, and then they are returned to the fallers to be scoured in a still stronger solution of soap. This solution is strong enough to produce an actual lather, and the remains of it are thoroughly washed out with cold water, which finishes what is called the *cleansing* process. The whitening effect of indigo when laid on a yellow ground is very remarkable, and is well known to laundresses.

When the operator has *very fine* goods to bleach, he has recourse to a process somewhat different, which consists in immersing them in a very hot solution of soap, with the addition of a little ground indigo. The hot soap gives them a gloss which is much approved of and occasions them to handle better than common hose, and the indigo improves their colour. The common goods are immersed in indigo and water only.

When all these successive operations have been duly practised, the hose are then removed to the drying stove, where care is taken that they shall be dried completely. From this they are carried to a room called the brimstone stove, where they are entirely enveloped by the vapours of sulphurous acid gas, arising from the burning of sulphur in a close chamber.

The use of this process is to decompose any portion of soap that may still be attached to the surface of the goods; for it has been found that, if they are laid up for any considerable length of time without their having undergone this operation, the smallest portion of soap remaining in them will occasion them to turn yellow. The manufacturer would, indeed, be glad to dispense with the use of soap altogether; but there is no article besides this that will effectually take away the smell of the chlorine gas.

When the hose are returned from the brimstone stove, they are slightly damped with common water, to prepare them for the finishing operation, known by the name of *dressing*. This consists in drawing each stocking separately on a stocking-leg board, in which state they are either put collectively into a powerful press, or ironed singly with a hot box-iron.

These are the methods which are generally adopted in bleaching and finishing thread and cotton hose[58], and they appear to be so well adapted to their respective purposes, that but very few remarks upon them will be needful.

It occurs to me, however, that the goods might be materially injured were they ever to be put into the brimstone stove in a damp state; for the vapour would then be condensed upon them in the form of

[58] The prices at Nottingham, for bleaching and finishing hose, are generally from 2*s*. to 2*s*. 3*d*. per dozen pair; for pieces of calico measuring 28 yards the usual charge is 1*s*. 6*d*. per piece.

sulphurous acid; and when treated afterwards with the hot iron, this acid would become concentrated and impair the texture. When the hose are dressed by the press only, it is not so necessary to attend to this circumstance. Another injury would result from this management, viz. that, being put damp into the stove, some parts would retain more water than others; and here, I conceive, dark spots would arise should the goods be laid by for a considerable time undisturbed, a circumstance which often actually happens in the shop of the retailer.

Only one thing more occurs to me, which is this, that the omission of weaving the blue and the red lines in the top of hose which are intended to be bleached, will conduce to injure the credit of the manufacturer in foreign markets [49]. I propose, however, to offer a few remarks on this at the close of the Essay.

Nothing has yet been said of the method of bleaching CALICOES for the use of the *printer*; for this embraces a great number of questions, and is a subject of very considerable difficulty. The following is the process which is generally adopted in the neighbourhood of Manchester, and throughout the county of Lancaster.

When the goods have been fired to remove the nap, as described in Essay IV. vol. i. pages 262, 263;

[49] At the desire of a respectable bleacher in the county of Nottingham, I published a few years ago some observations on this subject in the *Tradesman's Magazine*. See vol. ii. p. 105.

they are steeped for a certain time in pure water, usually until so much of the impurities is loosened from them as occasions a very sensible fermentation in the water, the time varying from twelve to twenty-four hours; or in soap and water, or in an alkaline lye which has been already used in the process of *bucking*, or bowking, as it is commonly called in this district. This appears to me, however, to be a very bad practice, because such lyes are always very dirty and loaded with resinous matter and other filth of a similar kind to that which it is the object of the bleacher to remove. How much better would it be to boil down such waste lyes, or evaporate the water from them by means of a vane to be turned by the steam engine, and then to recover the alkali by some economical process! Nothing but pure water, or clean lye, or good white soap and water, ought ever to be employed for these steeps. The temperature at which this steeping is conducted varies from that of 100 to 160 or 180 degrees, according to circumstances or the particular views of the operator.

The pieces are then washed in pure water; in large works this is done by means of a dash-wheel, which washes them more effectually than they could be by any other method; and then they are immediately bucked[60], or boiled in a solution of

[60] For an account of the bucking apparatus, see the description of the plates which accompany this volume, and also page 271 of this Essay.

caustic potash, and the boiling is continued for eight or ten hours. From the boilers they are again taken to the wash-wheel, and cleansed thoroughly. The process of boiling is repeated two or three times, taking care to wash well after every operation. Each of these boilings is usually continued for the same length of time, but care is taken that the alkaline lixivium be reduced in strength at every repetition of the process. In large concerns, where the process of bleaching is continually going on night and day, the boiling is generally done in the night, and the subsequent operation of washing is performed in the day time. After two of these boilings, some people pass the goods into the sours, whereas others do not sour them until they have been three or four times boiled.

The goods are then laid on the grass for two or three days; or, if crofting be not employed, an effect, similar to that which would be produced by exposure to the atmosphere, is obtained by an immersion in a solution of chloride of lime, of about the specific gravity of 1·005. In this they steep for twelve hours; and then they are removed into sulphuric acid, diluted with about forty times its weight of pure water. Mr. Murray says that this last souring imparts a much finer whiteness to the cloth than it would acquire without this treatment, as it dissolves the remaining colouring matter which had resisted the action of the alkali and oxygenated acid, as well as a small quantity of iron contained in all

vegetable matter, or deposited on the cloth from the alkaline lyes[61].

After this, the pieces are washed with the greatest care in successive portions of water, and are then hung up in the dry-houses, to be dried completely for use, by a current of atmospheric air, which is perpetually passing through them.

When the operation is to be performed on fine cloth, it is usual to boil once or twice more in a still weaker solution of potash, and to finish them in strong sours, made by the mixture of one measure of sulphuric acid with 46 measures of water, or one pound of the acid to twenty-five pounds of water. This is not because fine cloths require the most bleaching, but on account of such cloth being generally used for the finest kind of printing; for the heaviest pieces are generally the most difficult to bleach perfectly. In some houses it is customary to lessen the weight of the potash one-third for every subsequent boiling.

Some printers, instead of potash, use lime water, and others even cream of lime for the first bowking; washing and souring being adopted the same as if potash were employed; but in these cases care is taken not to allow the liquor to acquire more than a scalding heat.

This is truly a cheap method; but I conceive it to be a very bad practice, because where this mode is adopted plenty of selenite will unavoidably be

[61] Murray's *Chemistry*, 2d edition, vol. ii. p. 660.

formed in the cloth, and nothing will perfectly remove it. It is well known to many printers whose works are situated upon rivers, that if a piece which has been thoroughly prepared, should by accident drop into the river at the time of flood, when the water is charged with earth, it would be entirely spoiled for the madder copper. No kind of souring, nor any mode of treatment, which we are at present acquainted with, would repair the injury.

Some printers use the common potash of commerce, while others employ an alkali which has been made completely caustic by lime; others, again, mix a portion of soft soap with the potash for one or two of the first bowkings; so far are these manufacturers from being agreed as to every particular respecting these operations.

I must not, however, forget to mention that in large works, after every process of ashing, souring, or bleaching, the pieces are submitted to a powerful press, usually one of Bramah's, to force out the chemical liquor which remains in them; and that it is from the press they are taken, either to the river or the wash-wheel, for further purification. Some of the printers have not yet adopted the use of the press; but the professed bleachers are aware of its importance, and employ it constantly. In several works, I find it is a common practice to pass the goods through a pair of wooden rollers made of sycamore: these force out a great deal of impurity, and they make all the pieces of an equal dryness. This is not general, but I consider it to be

an eligible practice, and that it ought to be performed after every operation.

Although I have now given a short account of the processes which are employed in bleaching common calicoes, or what is known in some districts by the term of *surface-bleaching*, I still consider the series of operations to be very imperfect, because the goods thus bleached are often unfit for the purposes for which they are intended, and very frequent and serious losses have been sustained in consequence of it, as every printer can testify. This is very severely felt by those who print for hire, as such printers are expected to make allowances for all imperfect work, and these are often so enormous as to absorb all the cost of materials and the expense of printing.

A knowledge of this circumstance first induced me to turn my attention to the subject of bleaching; and the hope of being able to offer some useful hints to the consideration of practical men laid the foundation of this Essay.

From frequent and repeated conversations with many of the most intelligent bleachers in various parts of the kingdom, I have, I presume, clearly ascertained that, in preparing goods for the purpose of calico-printing, the following are the most important desiderata.

First. To form such a preparation of bleaching liquid, with the respective materials so nicely balanced, that neither the salt, nor the fluid which

which remains after the abstraction of the chlorine, shall have any injurious effect upon the fabric of the cloth. Those who bleach with chlorine should never lose sight of the circumstance, that common muriatic acid is always produced at the moment when the oxygen of the water unites with the colouring matter; and that this acid, if not corrected by other ingredients, will have an unfavourable action on the goods under operation. Sir Humphry Davy says, that he has tried the muriate of lime which remains after the common process of bleaching, and that he found cloth which he boiled in it to be considerably weakened; but that, if chloride of magnesia were substituted for chloride of lime, the muriate of magnesia which results would not impair the fabric.

Secondly. To bleach the calicoes in so perfect a manner that each piece of every parcel shall be completely fit for madder-work; that is, when cleared after being dyed in a madder-copper, that the whites shall be uniformly good and free from those stains which the superintendants in this department of our manufactures call *spangs*. For this purpose, some manufacturers lay great stress on the use of an apparatus somewhat similar in its principle to a Papin's digester, and known by the name of a *whale-boiler*. For a description of this vessel, see the Plate No. XXI. and the explana ion of it at the beginning of this volume.

Thirdly. To prepare calicoes, so that they shall readily take a light and uniform shade in the blue

vat. Cloth dried in summer and in the open air, when the atmosphere is dry and warm, dips much more freely in the blue vat than that which is dried in winter, especially in frosty weather, when the pieces require more exposure. In like manner, stove-drying is never esteemed so good as tenter-drying, for any purpose of fine printing.

In dipping pale blues, the printer often sustains great loss by the pieces coming out of the vat with white streaks, so as to render it necessary to bleach them afresh, and then to appropriate them for the reception of other colours. This is occasioned by a substance existing in the cloth, which resists the action of the blue-vat, and yet is not of sufficient consequence to rise to a spang when it is afterwards passed into the madder copper.

Every man has a different process for preparing his blue-vats; therefore the want of uniformity in the shade of these colours may sometimes arise from the vats being in bad order, or it may be owing to the employment of bad indigo. I would suggest that it might perhaps be advisable to appropriate a vat of either the finest Guatamala, or of the purest East Indian indigo, entirely to the purpose of dyeing *pale* blues; and that where the style of work will allow of it, (though it often will not,) it might be worth while to try whether superior dunging, previously to the blue dipping, would prevent the evil complained of.

Fourthly. To prepare any number of pieces

which shall be fit for both the above purposes, yet still be preserved perfectly sound.

It is evident to me that, in effecting these points, the main difficulty originates with the weaver; and therefore, to those who are not conversant with the business, it may be advisable to explain how this happens, before we attempt to suggest a remedy.

The weaver of calicoes generally proceeds thus. Having a fine warp delivered to him, frequently spun beyond what the staple of the cotton authorizes, and consequently not capable of bearing much hardship, he is compelled to throw in as much weft as will make the cloth of a very close texture; his only aim being to accomplish this object with the least possible trouble, and at the least expense.

As soon, therefore, as he has fixed the warp in the loom and stretched it out ready for weaving, he dresses it[62] by rubbing it longitudinally between two brushes which have been previously dipped in a paste made of potatoes, or flour and water. This paste is generally suffered to become sour before it is used, and frequently it is kept in an *iron* kettle till this change takes place.

When this dressing has become dry, in order to make the warp still smoother, he applies a different dressing, made with such greasy or oleaginous matters as he can the most easily procure. This generally is either tallow or butter, and is sweet or ran-

[62] See Essay IV. vol. i. page 264.

cid, as may accidentally happen; but tallow is the article which is the most commonly used, and it is applied in the following manner. The weaver having prepared a hot iron, he takes that in one hand and a lump of tallow in the other, and pressing them together, the tallow becomes partially melted and drops in patches on various parts of the warp. This is afterwards dispersed and spread over the whole warp, by means of the brushes which were employed to spread the paste before mentioned.

Instead of tallow, why might not soft soap be employed? It would be desirable for some manufacturer to give this a fair trial. Should it answer the weaver's purpose, it might afterwards be readily removed by washing. See an observation on this subject in vol. i. page 264.

It will be manifest to those who have considered this mode of procedure, that the subsequent spreading of the tallow cannot be effected without the grease being left in the largest quantity on those places where it was first applied[63]. Accordingly, it is found that these spots are often particularly discernible when the goods come to be dyed, although the operator may have supposed that they were well cleaned, having undergone the usual routine of steeping, boiling, souring, bleaching, washing, printing, and dyeing. For an account of somemethods for examining the goodness of the

[63] May not this be the origin of what are called copper-stains, mentioned in the following paragraph?

bleaching of white calicoes, see the Essay on Calico Printing, vol. i. page 265.

Printed calicoes are also often stained in larger blotches, though not so conspicuous as those just mentioned, but evidently arising from grease; generally covering a larger portion of the cloth, and very difficult to be removed. The workmen distinguish these by the name of *copper* stains, supposing them to have arisen in the madder-copper from an unequal application of the heat. This, however, is undoubtedly an erroneous opinion.

In reviewing the preceding observations the following questions suggest themselves.

If grease be the chief impediment to perfect bleaching, what are the best means of removing it? Are any of the alkaline solutions we have mentioned, capable of effecting its removal? In answer to this query, I would say, Take caustic potash, properly diluted with water, and not the *dirty* waste lye, an article often resorted to. For, in preparing for fine madder work, I am confident that what is considered to be a cheap, economical, and, I may be permitted to add, dirty mode of bleaching, can never do. On the contrary, for such work, the most expensive bleaching will generally prove to be the cheapest eventually; for the pieces have a better chance of being perfect, and the dyeing materials will go further.

Is soap (either soft or hard) of any service in the process of steeping, or that of boiling? Is lime of

itself a solvent for grease? If lime should be found to be adequate to this purpose, is there any probability of its injuring the texture of the cloth when used in the manner already described? And is there not some danger of particles of this earth remaining in the cloth after the most careful washing, and of its forming a sulphate of lime by immersion in the sours[64]?

When goods have turned out spangged, is it advisable, in order to prevent a repetition of the evil, and will it be consistent with the preservation of the texture of the cloth, to have recourse to more of the alkali, to greater heat, or to more frequent boilings? Or is any other plan preferable to all or any of these? Where perfect work is required, I conceive the proper answer to this query to be this. Let the alkaline lye be reduced in strength, and then let the usual number of boilings be doubled. That is, let them be boiled at least seven or eight times.

On the principle of boiling in a vessel somewhat analogous to a Papin's digester, what degree of heat can be employed with safety to the cloth? It will be seen, that in the common process of boiling the pieces, the lye being weak and exposed to the pressure of the atmosphere it can never much exceed the temperature of 212°.

What is the substance contained in cotton which resists the action of the blue-vat, or of cold water, and yet does not act as a mordant in the madder copper? I am disposed to think that this is a ques-

[64] For an answer to this, see pages 302, 303.

tion which, in the present state of chemical knowledge, no one is able to answer, although it is well known to every printer of the present day, that such a substance does exist, and that it often occasions much trouble and perplexity.

Is it originally in the cloth, or is it acquired during the bleaching process, or by the goods being improperly kept after they have undergone all the processes of bleaching? This is not likely ever to be the case; for I well know that the appearances to which I refer are often seen in goods which are dyed and printed directly from the hands of the bleacher.

What is the cause of those marks called copper-stains, already noticed? Are they owing to a portion of alkali being left in the cloth during the operations of bleaching, or may they be ascribed to insufficient washing after the process of dunging? These are certainly not copper-stains, but are possibly owing to improper bleaching. It is likely, indeed, in most cases, that these would not have appeared, had the bleaching been prolonged or the different operations oftener repeated.

The whole of these questions seem to arise naturally from a due consideration of this subject, and all of them, I believe, have at one time or other been proposed to me by various practical men, for my opinion; a circumstance which convinces me that much remains to be done before the art of bleaching calicoes for the use of the printer shall have attained that degree of perfection of which many other arts can already boast.

When the process of bleaching by chlorine was first practised, the art of calico printing may be said to have been in its infancy, and consequently very little variation was then made in the operation of bleaching the brown pieces, whatever might have been the style of work for which they were intended. When the competition was less, the perfection of bleaching was comparatively of small importance. But now the case is materially altered, and all the best printers know, that the common routine of processes, and such as I have described at page 312, is insufficient for bleaching calicoes which are designed for best madder-work. The common mode of bleaching is not sufficient, because goods so treated are never fully bleached *internally*; and, therefore, when they come into the madder-copper, the remaining impurities will in some measure rise to the surface, and there becoming a mordant for the madder, will occasion those parts of the cloth, which were intended to be preserved white, to acquire an indelible stain, or at least will inevitably produce what are called dull whites.

To remedy this, nothing will prove effectual, I suspect, but to increase the number of the operations, as mentioned above, and to conduct every process with the strictest regard to cleanliness, and to the purity of the articles employed. Here I had more particularly in mind the practice of using old dirty alkaline solutions; but it will also be equally impossible to produce fine bleaching where the goods, at all times of the year, can be washed only

in a river; because in time of flood the water will be charged with calcareous earth, which afterwards, when they are immersed in the sulphuric acid, will form an insoluble selenite within the pores of the cloth. Although there is an evident impropriety in using waste lyes, or such as had before been employed in any cleansing process, the most circumspect manufacturers, for common work or in what they call surface bleaching, do often boil such goods in a lye which had been used before in some of the latter processes of the finest bleaching.

Having had reason to conclude that many of the Scotch printers are already aware of this, because I know that a great deal of very excellent bleaching is accomplished in Scotland, I have procured from a scientific printer in that part of the kingdom, an exact account of the plan he pursues whenever he bleaches calicoes for madder-work, or resist-work, or for the fine pale blue-dipping, and which he assures me I may recommend with confidence. The following concise outline of the process will, I trust, be sufficiently explicit to be understood by every practical man.

The goods having been singed and steeped in pure water, as is customary in common bleaching, they are passed through a pair of rollers to press out the impurities which have been loosened by the steeping. It must here, however, be observed, that where the expense of one extra dyeing can be afforded, the process might be very much improved by steeping the brown calicoes for thirty or forty

hours *before* singeing, because this would separate much of that impurity which usually becomes fixed in the stuff on its being passed over the hot cylinders. When the pieces have been thus singed, steeped, and pressed, they are boiled four times, ten or twelve hours at each time, in a solution of caustic potash, of the specific gravity of from 1·0127 to 1·0156, washing them carefully and thoroughly in pure water between each of these boilings. They are then immersed in a solution of the chloride of potash, originally of the strength of 1·0625, and afterwards reduced with twenty-four times its measure of water. The specific gravity of the chloride of lime or of potash, is not an absolute rule for the determination of the bleaching power of either; for, sometimes the specific gravity will be what it ought to be, and yet the liquor, owing to the impurity of the materials, will be nearly effete. For this reason, the solution of indigo is generally employed to ascertain the goodness of all bleaching liquors. When the preparation is good, the proportions mentioned above will whiten cotton goods completely in eight hours. In this preparation they are however generally suffered to remain twelve hours. It is of importance to remark, that here the common bleaching liquor (chloride of lime) cannot, without injury, be substituted for chloride of potash.

Some printers take the pieces from this solution, and, while wet, lay them on the grass, and there expose them to the sun and weather for two or three days. From thence they are removed to the sours, made of the specific gravity of about 1·0254

at the temperature of 110 degrees of Fahrenheit. In bleaching common goods, and such as are not designed for the best printing, the specific gravity of the sours is varied from that of 1·0146 to that of 1·0238, if taken when they become of the temperature of the atmosphere. In these they are suffered to lie for five or six hours, after which they are taken to the wheel and washed thoroughly. When this operation is finished, they are submitted to four more boilings as before, with a solution of caustic potash; taking care to wash well between each of these boilings. Sometimes *pearl-ash*, made caustic, is used for the last of these boilings, lest the sulphur, which always exists in the potash of commerce, should impair the whites. They are then immersed in the diluted chloride of potash, of the strength before mentioned; after which they are well washed in pure water, and then winched for half an hour in common sours. The last process is that of careful washing in plenty of clean water, after which they are not put into the stove, but are immediately hung up in the airing sheds to dry gradually. I know several print-works where it would be impossible to produce fine bleaching, because they are not supplied with a sufficiency of water. For this purpose the water must be good, and there ought to be plenty of it at all seasons.

The number of operations, as here described, is great; but I know of no other mode of procedure by which perfect bleaching is so likely to be effected at all times and in all seasons, without disappoint-

ment. It must here be remarked, that, for the best purposes of printing, it would not be sufficient to take goods which have been bleached in the common way and finish these by the better process; because the selenite deposited in the cloth by that operation, will for ever spoil them for madder colours; at least, a printer who is curious in his work would not dare to use such for those purposes.

I have, however, been informed that the proprietors of some of the Scotch establishments still persist in bleaching calicoes without any preparation of chloride whatever; and one of the partners in a concern of considerable consequence in the county of Chester, has also assured me that he has always continued to bleach by the old method; and that he has nothing to depend upon but the frequent repetitions of the alternate processes of ashing, souring, and crofting, for the production of good whites. It nevertheless appears to me, that this must occasion great waste of time, and, where the calicoes are to be employed for the best work, must be very uncertain in the result. Knowing that good printing is regularly produced at this establishment, I confess I do not understand how the proprietors contrive to succeed without the employment of a solution of chloride of lime, or some such substance.

In the Essay on Calico Printing I have already remarked that the German linen cloth is better than the Irish; and yet, in consequence of the Irish cloth being bleached and finished in a superior manner, that this has always the preference in fo-

reign markets. In endeavouring to account for this, I apprehend we must look to an important national institution, known by the name of the *Linen Board* of Ireland, which has done every thing in its power to improve the staple article of the kingdom, and has the sovereign controul in every matter relating to the linen manufacture. Some of their regulations deserve to be mentioned.

In Ireland, every bleacher must stamp his own name on the end of every web[65]; hence it can always be ascertained, by mere inspection, where the bleaching has been performed. Again, should any goods be improperly bleached, so that the texture is injured, the bleacher is liable to be compelled to take back the whole of them, and pay every expense of carriage, however far they may have been conveyed from the spot where they were finished. In this case the bleacher is also subjected to a considerable fine. So certain is the infliction of this penalty in case of a complaint being properly lodged against a delinquent, that some years ago, when the bleaching process was not conducted with that care with which it is at present, several persons actually travelled through many of the counties of England and Scotland for the purpose of collecting from the mercers all such damaged Irish linens, and for which they paid good prices, in order to be entitled to receive the fines.

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[65] A *web* is a technical term among all weavers and bleachers, both in Great Britain and Ireland, for a piece of linen cloth.

The best regulations may, however, be superseded and often evaded. Accordingly it is well known that many hundred thousands of pieces of calicoes are made and finished in Lancashire, and stiffened in a peculiar way, to imitate the Irish linens, particularly those made at Colerain, and that they have the name of this place stamped upon them. Is not this a proper subject for the interference of the legislature? though the Irish, in their turn, practise, as I understand, a similar deception in the manufacture of thread.

It is notorious that a kind of linen thread made at Paisley, in Scotland, and known by the name of Nuns-thread, has the preference, and is the best for use. In consequence of the character which this thread has acquired, the Irish have now begun a similar manufacture, and scruple not to usher theirs into the market under the sanction of a stamp bearing the name of *Paisley*.

In like manner, an article called *Inkle*, and some species of thread resembling that which is made in Holland, are now manufactured in large quantities in Scotland, and sold under a Dutch stamp; the method of making these articles having been stolen from Holland, and brought into Scotland half a century ago. Thus, self-interest is apt to be the leading motive with mankind in all nations.

In resuming the subject of bleaching, it will be necessary to mention that the chloride of soda, spoken of in describing the mode which the Scotch printers adopt in bleaching calicoes, is now em-

ployed also in clearing the whites of maddered goods, and that this has almost entirely superseded the operation of crofting, which was a tedious and expensive process [66]. The method is to mix a small portion of the chloride of soda with a large quantity of warm water, and then to suffer the maddered pieces to lie in this preparation till the grounds become perfectly white.

This, which is one of the last improvements in calico printing, is of very considerable importance; for, the finest ginghams, as they are called, and the most expensive chintz work, which contain a variety of very delicate colours, and formerly required many weeks exposure on the grass, can now be cleansed in a few hours, so as to produce the most perfect whites, without impairing any of the colours themselves.

In conducting this process, it is of the utmost consequence to attend to the precise strength of the preparation of chlorine [67], that it may be strong enough to clear the whites completely, and yet incapable of discharging or impairing any of the printed colours. This is usually ascertained by means of a very dilute solution of sulphate of indigo, prepared in the following manner.

One pound of the best Spanish indigo that can

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[66] This application of the chloride of soda has already been slightly mentioned in vol. i. page 284, and at page 304 of this volume.

[67] I have procured a drawing of one of the most approved of the apparatus now employed for making the chloride of soda for this particular purpose. See Plate 20.

be procured, is to be dissolved by the usual method, in four pounds of concentrated sulphuric acid. These proportions will generally saturate each other. When the whole of the indigo is dissolved, one part by measure of this solution is to be diluted with sixteen parts by measure of water, and then it will be fit for use. To obviate any deception which might arise in case of a difference in the quality of the indigo, it is always best to preserve some of the old solution, and then, having compared the new with this, to alter the proportion of water a little, if this be found necessary. The quantity of water which is employed in diluting the solution of indigo is not very material, provided the operator accustoms himself to the use of one certain determinate proportion; and indeed this test is used of various degrees of strength according to the fancy of different printers; but one printer should always use it of one particular strength.

The object in making this preparation is to have a standard always at hand, by which the printer can with precision ascertain the exact strength of any of his bleaching liquor; and this is always to be determined by the quantity of it that is required to destroy the colour of any given portion of the test, or *vice versâ*.

In employing this reagent, it is customary to have two long graduated glass tubes, in one of which the diluted sulphate of indigo is put, and in the other the bleaching liquor. By gradually pouring some of the former into the latter, it is

immediately seen how much of the coloured test is destroyed, by a given number of parts of the preparation of chlorine. This, however, for the reasons already adduced [68], is not a sufficient test of itself for ascertaining the goodness of a bleaching liquor without attending also to its specific gravity.

Berthollet has, indeed, said that Mr. Watt had told him that the indigo-test will not accurately show the strength either of chloride of soda or potash; and he also adds, that a decoction of cochineal is a better test, for that it completely answers every purpose, and is not liable to occasion any deception. I know not, however, on what principle this opinion is founded.

While speaking of tests, it may perhaps be worth while to mention, that this same eminent chemist has proposed the bleaching liquor itself as a useful test for proving the goodness of colours on printed calicoes. By taking a shred from the piece of calico intended to be tried, and another shred of a similar colour from a piece known to be printed with *fast* colours, and then putting both pieces at once into a preparation of chlorine, it will soon be seen which pattern can best resist the power of the bleaching fluid.

The compressed steam of boiling water has been lately employed instead of chlorine in bleaching cottons. It is said that this method of bleaching has long been practised in some parts of the East.

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[68] See page 297 of this volume.

Chaptal was the first writer who recommended it to the European bleacher [69]. By the continued and alternate immersion of cotton goods in an alkaline liquor, and the exposure of them to the action of the vapour arising from the same lixivium when heated to 220° or 230°, the goods are said to be whitened very effectually without the fabric sustaining any injury. The resinous and other colouring matter of the cloth, which is insoluble in a dilute solution of alkali at the temperature of boiling water, becomes soluble in this menstruum, when heated a few degrees beyond that point. The operation consists, first, in immersing the goods in the alkaline lixivium, and then exposing them to the heated aqueous vapour; and these methods are pursued alternately till the whitening is completely attained.

This mode of bleaching linen goods has been adopted in France for domestic washing. Chaptal tried it on 200 pair of sheets belonging to the hospital of the Hotel-Dieu of Paris, with the utmost success. The linen was perfectly cleansed, and the expense was reduced in the proportion of four to seven [70]. I have had no opportunity of observing the effect of this process myself: but I can easily conceive that a superior temperature may be of

[69] See his *Chemistry applied to the Arts*, vol. iii. p. 100. Delamétherie also wrote a memoir upon it in the *Journal de Physique* for the year 1801, at p. 305, of which some account may be seen in Nicholson's 4*to Journal*, vol. iv. p. 469.

[70] For the details see *Annales de Chimie*, tome xxxviii. p. 291.

service in bleaching [71], because I have noticed that when brown calicoes, which have undergone only *one* boiling, have lain all night in the kier, or whale boiler [72], those parts of the pieces which had been in immediate contact with the iron fountain, standing in the middle of the apparatus, were quite white, while the others were very little improved in colour by the operation. This I attribute to the lengthened continuance of a high temperature, as a great degree of heat is always communicated to the middle of the vessel, by the constant circulation of the boiling liquor through the fountain, the metallic part of which, at times, may perhaps exceed the temperature of 212°.

The bleaching of linen and cotton goods by means of compressed steam, will however be always attended with some difficulty on account of the danger of the bursting of the apparatus by the force of the confined vapour, if the valves should ever be improperly loaded: but, notwithstanding this objection, it appears to me that the practice deserves further investigation; for it would doubtless be a great advantage to the arts, if it were possible to bleach our manufactured goods in as short a time as they are at present finished, and yet save the expense of chlorine altogether. The apparatus employed for this purpose in Great Britain is gene-

[71] Several instances of changes produced by alteration of temperature may be seen in Essay II. vol. i. page 176—194.

[72] For an explanation of the nature of this apparatus see the description of the plates which accompany this volume.

rally made with large slabs of stone cramped together with iron, and sufficiently massy to sustain the effects of great pressure[74].

It was originally my intention to have offered some remarks on the methods of bleaching wool and woollen goods, silk, bees-wax, writing paper, books, prints, &c.: but as the Essay has already exceeded its prescribed bounds, I must content myself by merely referring the reader to the sources from whence he may obtain some information on these subjects.

Wool has usually been bleached by the fumes arising from the slow combustion of sulphur, an article which was employed sixteen hundred years ago for the same purpose It has, however, been found that this mode only whitens the surface of the goods: therefore, of late years, recourse has, in some instances, been had to the *liquid* sulphurous acid, which bleaches wool more effectually than that acid does when in a gaseous state. Some account of the usual process by the means of sulphurous acid gas, may be seen in Pajot Des Charmes' Art of Bleaching, translated by Nicholson, 8vo. London, 1799, page 280 The burning of brimstone in atmospheric air is called the *slow* combustion, in opposition to the burning it in oxygen gas, or by the mixture of nitre; but Stahl has shown that in bleaching woollen, the slower the

[74] An ample description of that used in France may be seen in a work by M. D'Orelly, entitled "*Essai sur le Blanchiment*," sold by Deterville, Paris.

sulphur is burnt, the more effect will it produce. Apuleius, who lived in the time of the Antonines, tells an anecdote, in the romance of the Golden Ass, of a man who had an illicit amour being nearly suffocated at the house of a fuller, by having hid himself under a wicker coop which had been employed to whiten cloth by the fumes of burning sulphur [75]. It appears from this story, that the ancient fullers bleached their woollen cloths by hanging them round an apparatus made of wicker work, and then setting fire to a portion of sulphur placed underneath it. Messrs. Roland, Laplatiere and Allard, who were general inspectors of manufactures in France, published several memoirs on the bleaching of wool, and the above account by Charmes appears to have been taken from these papers.

In bleaching bees-wax the following is the process, as it is usually conducted in England. Common bees-wax is melted upon hot water; and when in a fluid state, it is laded out of the copper, together with a part of the water, into a wooden vessel, and in this it is allowed to remain a few hours for the impurities to subside from it. The purified wax is then put, while still hot, into a cullender full of holes, through which it runs, and falls upon a revolving metallic roller, which dips into cold water contained in a vessel placed underneath. As the melted wax runs through the cullender upon the revolving roller, the motion of the cylinder forms it

[75] See book ix. p. 136, edit. Scrivenii, Amst. 1624.

into thin shavings, which cool as they come in contact with the water, and fall in an accumulated heap into the water below. These shavings of wax being now in a suitable form for absorbing oxygen, they are taken out of the tub, and exposed in a field to the action of the atmosphere till they become sufficiently white.

A memoir by Baumé on the bleaching of silk will be found in Nicholson's 4to Journal, vol. i. pp. 32 and 88. This memoir, which is extremely interesting, was first published in the Journal de Physique [76]. The method consists in digesting the silk in a large quantity of spirit of wine previously mixed with a few ounces of muriatic acid. Some account of the bleaching of bees-wax may be seen in Fourcroy's System of Chemistry [77].

The specifications of several patents which have been obtained of late years for divers modes of bleaching paper, may be read in the Repertory of Arts: and ample directions for bleaching old copper-plate engravings and old printed books, will be found in Chaptal's System of Chemistry applied to the Arts, or in the English translation of that work [78]. A memoir by Loysel on the bleaching of pulp for making paper may be seen in the Annales de Chimie [79].

Sig. Fabbroni, Superintendant of the Royal Cabinet of the Grand Duke of Tuscany, communi-

[76] Tome xlii. p. 375—399.
[77] Vol. x. p. 483, and in Charmes, p. 207.
[78] Chaptal, vol. iii. p. 108.
[79] Tome xxxix. p. 137.

cated to Dr. Duncan, jun. of Edinburgh, a very simple and ingenious mode of bleaching old prints, which may be found in Nicholson's 4to Journal, vol. ii. p. 265. Chaptal presented an Essay on this subject to the Academy of Montpellier, and this was afterwards published in the Memoirs of the Royal Academy for the year 1787. The Report of Messrs. Lavoisier and Berthollet on this paper may also be seen in the Annales de Chimie, tome i. p. 69.

The art of bleaching has also been introduced of late years into the straw manufactory. The manufacture of straw into the form of hats for females has become very considerable, and consequently important, especially as it gives employment to a very great number of the children of the poor. I have not yet learned the methods employed for bleaching the straw when it is intended for *white* hats, but a friend of mine has assured me that the *sulphurous acid* is employed. This acid is very effectual for the removal of fruit stains from linen or cotton garments. All that is necessary is first to damp the places thoroughly, and then to burn two or three common brimstone matches close to them. The gas from the sulphur will combine with the water and form sulphurous acid, which will very soon occasion the spots to disappear.

The chlorides have also been applied to this purpose, but they are said to weaken the vegetable fibre. This, however, must be owing, as I imagine, to their being employed in too concentrated a state.

I have now only to make a few desultory observations which I conceive may be useful, and with these I shall close the Essay.

In a large bleaching establishment it is of great importance to know how to procure manganese of the best quality. There are several mines of this mineral in various parts of these islands; but I know of none equal to that which is raised at *Upton Pine*, in the county of Devon. Most other kinds are of little value to the bleacher, inasmuch as they require a larger portion of sulphuric acid and yet produce less oxygen. Even the manganese from Upton Pine is of various qualities. That, however, which contains the largest proportion of the crystallized oxide is generally to be preferred.

Being desirous of obtaining the best information respecting manganese, I took an opportunity, in the year 1810, of visiting this celebrated mine, where, from the proprietors themselves and from some of the intelligent inhabitants of the neighbourhood, I learnt several particulars which may be worth recording.

This mine is situated between the two turnpike roads from Exeter to South Moulton, and from Exeter to Crediton, and, as far as I could collect, had then been worked about forty years; though at first the quantity of the manganese that was raised was small, as it was then employed only in the manufacture of glass, and in some processes in the Staffordshire potteries. This mine, which produces the best oxide of manganese that has ever been raised

in these kingdoms, was accidentally discovered by a person passing along the road; as the mineral originally came out at the surface of the ground, and the roads in the neighbourhood were occasionally repaired with it. The mine is on the estate of Sir Henry Starford Northcote, Bart. of Pines-house; and I learn that the first persons who occasioned it to be worked were Nicholas Williams and Zachariah Kingdon, of the city of Exeter, Esquires, who acquired much wealth by the profits of the undertaking. Both these gentlemen being since dead, and the lease having expired, the mine is come into other hands, and the sum paid per ton for the royalty is very much advanced.

Some thousand tons of manganese and loose earth having been removed, the mine is now in such a state as to allow persons to descend into it by a winding path cut within the hill, and which conducts to the foot of a perpendicular rock fifty feet high. The entrance into that part of the mine which is now worked is through an archway cut in the face of this rock. An immense quantity of manganese having been raised since this entrance was made, the excavations are now of considerable extent, the upper ground being supported by large masses of manganese which are left for pillars. Here, by help of a pick-axe, I broke off some fine specimens of the mineral.

At some distance from the entrance of which I have been speaking, two shafts are sunk of the depth of fifty feet each, which lead to the lowest part of

the mine, and which I was desirous of exploring, as I could distinctly hear the men at work under my feet: but being told that I could not descend without being thoroughly wet, and having no dress with me fit for the undertaking, I was induced to decline the offer which the superintendant made of accompanying me. In order to drain the mine as well as possible, without an engine, they sink as low as they can in the first instance, and then work *upwards* to get the mineral. The part which I explored is 50 feet below the surface of the ground, and the part they were then working is 50 feet lower still.

The captain of the works informed me that the load runs north-east and south-west; and from his account I calculate that it dips regularly at an angle of 40 degrees. In some places the vein is twelve feet thick, in others not more than two feet. The capel, as they call it, which covers the mineral, is a hard rock composed of a mixture of sand, red clay, and manganese. Notwithstanding the increased demand for the oxide of manganese, for the purposes of bleaching, it seems likely that this single mine may be capable of supplying the whole island for a century yet to come.

It is usual with the bleacher, to cast away the residuum of the stills as a worthless article; but surely if some competent person were employed to separate the sulphate of manganese from the sulphate of soda, and this were done on the spot where the residuum is produced, the alkaline sulphate would be productive of considerable profit. In like man-

ner might the waste solutions of chlorine be turned to a good account. The discovery of Humboldt, that a weak solution of such preparations has the property of accelerating and enlarging the growth of vegetables, I have already noticed under the article Chlorine in The Chemical Catechism, 10th Edition, chap. vii. page 153; and I am now anxious to remark, that gardeners whose grounds are in the neighbourhood of bleach-fields, would do well in availing themselves of all the advantages their situation affords them for making experiments on this interesting and important subject. Berthollet, in the memoir already mentioned, observes, that he had himself abstracted the soda from this residuum, but that he could not explain the methods because they were confided to him as secrets. Whatever difficulties may attend the production of soda from this refuse, surely *sulphate* of *soda* might be easily separated from it, and this would always meet a ready sale under the name of Glauber's salt.

Since writing the above, I have been introduced to a gentleman resident in the midst of the Lancashire bleachers, who has constructed a large apparatus consisting of boilers and crystallizing vessels, for purifying this residuum, and has completely succeeded in procuring from it many tons weight of very fine Glauber's salt. Government has however lately forbidden the sale of the residuum; and consequently this extensive apparatus is become useless.

A very worthy company of Scotch bleachers with whom I am acquainted, and who have built several

hundred cottages on their estate for the use of their workmen and their families, have occasionally put this residuum to the following valuable purpose, which merits public attention.

Whenever there is an appearance of fever in any one of these houses, one of the managers orders the whole of the family out of it; and then placing a pan containing a portion of this residuum, recently taken from one of the stills, over a chafing-dish of burning charcoal in the middle of one of the lower rooms, he shuts up the house, that every part of it may be completely filled with the chlorine gas, which the heat separates from these materials, and which quickly neutralizes or destroys all the putrid miasmata, and renders the habitation perfectly safe and wholesome. This practice has been adopted for the last twenty years, and during the whole of this time there has been no virulent or infectious fever in any family belonging to the manufactory[80].

In resuming the subject of bleaching, it is necessary to remark, that too much attention cannot be paid to the method of ascertaining the strength of the bleaching liquid. I have reason to believe that many bleachers rely solely on the evidence which the specific gravity affords them, for any knowledge they obtain of the goodness of their preparations of chlorine. I would therefore once more warn these people against such reliance, and again

[80] See a Report on the Construction of Mephitic Engines in the *Annales de Chimie*, vi. page 86—120.

urge the necessity of having recourse to the Saxon blue, already recommended, or to some other infallible test in addition to the proof afforded by the specific gravity; it being impossible ever to acquire a sufficient knowledge of the real bleaching power of the liquid, without employing both these methods in conjunction.

In bleaching with chlorine, it is also of consequence to expose all the surfaces equally, and in proper succession; for, when the goods lie one upon another, the gas does not properly penetrate them, and they are never uniformly bleached: whereas, in the bucking process, with the solution of potash, they are disposed as it were in masses of a considerable thickness, and the operation still goes on well. It was probably the knowledge of this circumstance which has induced many bleachers to have their vessels constructed very broad and shallow; but this has occasioned another very serious inconvenience. The chlorides being more liable to lose the chlorine the greater the surface of the apparatus be in which the liquors are exposed, it is more difficult for the men to secure themselves from injury, and the waste is much more considerable. Where there is a contrivance for exposing all the surfaces equally to the action of the bleaching liquor, the *deeper* the vessels are in comparison of their diameter, the better will they be adapted to convenience and economy.

It is also important to rinse the goods immediately after they come out of the alkaline liquor.

It is no unusual thing for the manufacturer to allow them to lie in heaps for a considerable time before washing. But this I conceive to be a bad practice; for while the goods are warm the pores are open, and the filth which has been loosened by the recent action of the alkali, will be more effectually removed by washing *immediately* than if they be allowed to lie till they become cold.

In order that no waste of alkali should arise in the process of boiling or bucking the calicoes, it has been customary with many persons to use the lyes a second and a third time, as stated at pages 313 and 322, and often to the great injury of the goods which are so treated. Instead of this, I would advise, that all such impure lyes should be concentrated by evaporation, and, when of a due consistence, removed from the evaporating pan to the floor of a small reverberatory furnace similar to those described in the plates, and mentioned in the note vol. ii. page 69. Where there is a convenience for fully concentrating such waste lyes by evaporation, a common baker's oven might be employed for the subsequent calcination, provided the precautions were taken in heating it which are advised by Pajot des Charmes, p. 87 of his well-known work on this subject. In such a furnace they would easily be purified, because a gentle calcination would burn the colouring matter and restore the alkali to its original state. In districts where coal can be had cheap, and the consumption of alkali is considerable, this would be a very economical process.

Nothing now remains but to redeem the pledge which I gave at page 312, to offer a few remarks on the introduction of the blue and red stripes, which are often seen at the top of cotton hose. But these remarks must be very brief.

Since the introduction of chlorine in the process of bleaching hose, at least since its nature and operation have been so well understood, the careful bleacher is under no apprehension of injuring the articles which are committed to his care, and has no difficulty whatever in ascertaining the real quantity that may be absolutely necessary for the bleaching of any particular parcel of goods.

The remark of an eminent French writer very much confirms what I have said at page 298, on the preference which should always be given to chemical bleaching when properly conducted. "Thread bleached by the oxygenated muriatic acid," says he, "may be used by the sempstress with much more speed and briskness than thread of the same quality bleached in the field; it is less brittle, and may be struck much more effectually home to its place in weaving, and does not move afterwards. I received," says he, "this valuable information from impartial and unprejudiced manufacturers[81]."

Notwithstanding the bleacher of hose may easily determine the real quantity of bleaching liquid to be used, yet there is still considerable risk in the

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[81] Pajot des Charmes *on Bleaching*, translated by Nicholson, page 138.

process, and a danger of the texture of the articles being in some measure injured if the operation be conducted with carelessness, or by those who are unacquainted with the properties of the bleaching liquor. On this account, therefore, it is desirable that the public should be acquainted with a test that would in every case show, whether the chemicals had been properly applied or not; or, in other words, whether the goods which an individual may be about to purchase, have or have not been impaired by the process of bleaching.

The makers of thread and cotton hose were so convinced of the importance of having a test of this kind, that some few years ago the principal manufacturers adopted the practice of running a line of vat-blue thread dyed very dark, or of Turkey-red[84], along the top of each stocking; and those bleachers only were employed by them who could render the hose beautifully white, without effacing the blue or red stripes, or even lessening their intensity of colour.

The chloride of lime will destroy indigo-blue or the Turkey-red dye, if it be used of a considerable strength; and yet it may be so diluted, that it will be strong enough to bleach linen or cotton goods effectually, and still be incapable of injuring the colours above mentioned. On this account it appears to me that these dyes will always afford

[84] These are two of the most permanent dyes; but I know of no colour that will resist a very strong preparation of chlorine.

excellent tests for ascertaining when the bleaching process has been properly or improperly conducted.

Great advantages might indeed accrue to the manufactures of this country if the makers of plain calicoes, dimities, hempen cloths, cambrics, and Irish linens, as well as the makers of cotton hose, would adopt the method of running a line of such coloured threads along one of the edges of their goods, before they send them to be bleached; and that they would employ no bleacher who would not engage to preserve those colours entire, and of their original perfection or intensity.

Were this to become a general practice, the public would soon learn the importance of purchasing no goods but such as contain that badge of strength and goodness, and the nation would be sure of preserving that superiority in the foreign market to which it has been accustomed, but which has lately been so much endangered by the uncertainty with which the modern practice of bleaching has been attended. Until something of this kind be established, no one can be certain of the quality of the goods he purchases. In buying linen and cotton hose, he may indeed at present avail himself of the precaution I have been recommending, as there are now white hose in abundance in the market which contain these kinds of coloured lines in perfection, and which show that the goods have undergone the necessary ordeal, and have come forth from it uninjured. The design of this detail is to

convince the public, that it would be to their advantage to demand that the same attention should be paid to the bleaching of every other kind of goods, whether they be manufactured of linen or cotton.

It is a common practice in the neighbourhood of Manchester, in the process called *singeing*, as described at page 262 vol. i. of these Essays, to pass fustians and some other kinds of goods, in a damp state, over a red-hot cast-iron roller; and though every part of the piece comes in actual contact with the red-hot cylinder, the business is conducted so adroitly, that the goods sustain no injury whatever; whereas, if there were any irregularity in the movement, the goods must be burnt. Just so it is in bleaching. If the articles be suffered to lie too long in the bleaching liquor, or if that be improperly prepared, mischief will be done; but in the hands of proper people this can never happen.

The following are some of the sources from whence further information may be obtained on the subject of this Essay. "A Memoir on Hyperoxymuriatic Salts," by Dollfus, in Annales de Chimie, tome i. page 225.—"Additions to the Description of the Bleaching Process in France," by M. Berthollet, tome vi. of the same work, page 204.—"A Letter from M. D. Hellancourt to M. Lavoisier, giving an Account of the Method of bleaching Cloth in Beauvoisis in Flanders, and in Lower Picardy," tome vii. page 263—277.—"Memoir on

the Distillation of Manganese with Sulphuric Acid," by Vauquelin and Bouvier, tome vii. page 287.—"The Manner of preparing at all times, and in all places, and at little cost, a saponaceous Liquor for whitening Cloth." Pelletier, tome xix. page 349.

ESSAY XIII.

ON

WATER.

IN the beginning of the last century it was supposed, that there were four elementary bodies in Nature, and that this terrestrial world was entirely composed of those elements. Of these first principles, WATER was one; and consequently this was always considered to be a simple substance that entered into the composition of most other bodies, but was itself incapable of decomposition.

Boerhaave says, that it was in consequence of Moses having delivered a tradition that the Spirit of God, brooding upon the face of the waters, had communicated to them a prolific virtue, that the ancient Persians looked upon water as the principle of all bodies [1].

Many other ancient nations considered water to be the first principle of all created things. Milton likewise favours the idea:

[1] See Genesis i. ver. 2.

——— "On the watery calm
His brooding wings the spirit of God outspread,
And vital virtue infus'd, and vital warmth
Throughout the fluid mass[2]."

The same doctrine is also taught in the Koran. "Do not the unbelievers know that the heavens and the earth were solid, and I clave the same in sunder, and made every living thing of water[3]?"

Of late years, however, it has been discovered that this notion of the simplicity of water is erroneous, and that the four substances which the ancients had fixed upon as the simple elements of Nature are themselves all *compound* bodies.

Water is composed of oxygen and hydrogen in the proportions of 85 parts by weight of the former to 15 of the latter; so that 85 ounces of oxygen gas when united with 15 ounces of hydrogen gas will form 100 ounces of water. These are what are deemed the usual proportions: but they cannot be considered as absolutely and undeniably correct, because the quantity of aqueous vapour which the gases usually contain renders it difficult, if not altogether impossible, to produce an accurate estimate[4]. Some experiments by Ritter seem to prove that *frozen* water contains a less proportion of oxygen. These were communicated by Professor Jameson to Mr. J. Murray, who has given an interesting account of them in the 2nd volume of his

[2] *Paradise Lost*, book vii. line 234.
[3] See Sale's *Koran*, vol. ii. page 155.
[4] See a Memoir by Humboldt and Gay-Lussac on this subject in vol. liii. of the *Annales de Chimie*, pp. 239—259.

System of Chemistry. The most beautiful, and apparently the most decisive of these experiments, is that of diffusing in various portions of water a quantity of newly prepared white prussiate of iron, (a substance which, by the blue colour it assumes when it receives oxygen, is a very delicate test of that principle,) and excluding the action of atmospheric air by a thin layer of oil on the surface of the liquid. These vessels were exposed to various degrees of cold, and as soon as the water in either of them froze, the *white* precipitate became *blue*.

Since the compound nature of water has been understood, many ways have been discovered of decomposing and re-forming it from its original elements [5], so that there is now no longer the least doubt either of its composition, or of the proportion of each of the elements of which it consists.

Water may be decomposed by the agency of some combustible substances; also by means of common and Voltaic electricity. Vegetables of all kinds, while alive and fresh, are likewise furnished with organs for the decomposition of water, by which they appropriate its hydrogen and part of the oxygen to the formation of oil, sugar, starch, and numberless others of the combinations to which we apply the term *vegetable* principles.

Fish, especially those of the cetaceous tribe, constantly decompose water and live upon its hydrogen.

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[5] A description of Mr. Cuthbertson's apparatus for producing water by the combustion of hydrogen in oxygen gas, will be found in the *Philosophical Magazine*, vol. ii. page 317.

We have also reason to believe that some terrestrial animals are endowed with the same faculty. Count Rumford has very satisfactorily shown, that the surprisingly small quantity of solid food which is sufficient for nourishment when converted into rich and palatable soup, is owing to the culinary process having prepared the water for decomposition, and that this is ultimately effected during the act of digestion[6]. I suspect that tainted wooden vessels have the property of decomposing water. It is related in the Philosophical Transactions, that a company of English who had provided themselves with good wholesome water at St. Jago, which was put into hogsheads, found on their arrival at the Island of Borneo, that the water was become exceedingly fetid, and that it emitted a vapour which caught fire on a lighted candle being brought near it. An account of a similar change in some water taken from the Thames, may be seen in the same work[7]. It is a curious fact, that if an electric spark be passed through oxygen and hydrogen gases, whatever may be the proportions of the mixture, 85 parts by weight of oxygen and 15 of hydrogen will be the only proportions that unite to form water, and that the remainder will still continue in the state of gases.

There can be no doubt that water is also decomposed in many of our chemical processes, and that the effects which are produced in some of our

[6] Rumford's *Essays*, vol. i. page 194—202.
[7] *Philosophical Transactions*, No. 268, page 838.

manufacturing operations are owing entirely to this same cause. I will adduce one instance.

Considerable advantage is derived by the woollen-dyers from the use of water in the preparation of rasped logwood. As the wood is cut into chips, they sprinkle it abundantly with water, and in that moistened state it is thrown into large heaps, and sometimes into bins of great size, where it is suffered to lie as long as is convenient. By this treatment the chips become heated, or they ferment as the dyers call it, and thus undergo a very remarkable change; for, after having lain a few months in this state, they give out the colouring matter in the dyeing copper much more easily; and any given quantity of such chips will produce a more intense dye than could have been obtained from an equal quantity of chips which had not been thus treated. It is difficult to account for this, unless we suppose that the water becomes in part decomposed, and that its oxygen, uniting with the vegetable colouring matter, renders it more intense,—similar to the case of fruits, which deepen in colour as they ripen, by their gradual absorption of oxygen [8].

From the observations which I have made during the superintendance of a variety of chemical processes, I think I am justified in asserting that, whenever this subject comes to be thoroughly investigated, it will be found that water has more to

[8] See "A Memoir on the Colouring of Vegetable Substances by Oxygen," in *Annales de Chimie*, tome v. page 80—91.

do in influencing the results of most of the operations of nature and art than has generally been imagined. This will perhaps appear probable, when it is considered that water is a solvent for the alkalies as well as for almost all saline bodies, acids, and earths; and that by its decomposition it often imparts oxygen to one principle and hydrogen to another [9].

It is from this idea that I am induced to fix upon water as one of the subjects of these Essays, with a view of directing the attention of our various artists and manufacturers to this one particular point.

The subject is so important, and embraces such a variety of matter, that it would be impossible in the course of a short essay to enter into that amplification of detail which the matter deserves. A history of the different opinions respecting water, and of the progress of the various discoveries [10] in this branch of natural philosophy, will therefore not be expected; but if such evidence can be adduced as will be sufficient to convince the inquiring reader that the most common fluid we have, and that which is the least thought of, is capable of effecting the most important changes in the ma-

[9] This fluid must also possess the power of dissolving carbon; for by what other means can this be conveyed into the vegetable organs so as to form the ligneous fibre?

[10] The discovery of the decomposition of water has enlarged the sphere of chemical knowledge very surprisingly, particularly with regard to several phænomena respecting the metals, which otherwise must have remained totally inexplicable.

terials on which he operates[1], or of producing results which will at times disappoint all his expectations; something will be done towards informing the public mind, or, at least, the young manufacturer will be furnished with an idea that may be of use to him in the conduct of some of those processes which it will be his business to superintend.

Water exists in four separate and distinct forms, viz. in the state of ice; in that of a fluid; in the state of vapour; and in a state of chemical combination with other bodies.

The most simple form in which it is probable that water will ever be exhibited, is that of ice; for by the mere combination of ice with caloric fluid water will be formed, and a further portion of caloric will convert this fluid into steam, the most attenuated aqueous vapour being nothing more than ice dissolved and rarefied by the solvent and expansive power of caloric.

Besides these different appearances of water, which are familiar to every one, water is known to exist in chemical combination with other bodies, forming an essential part of their substance, and contributing towards the semblance, forms and qualities which they respectively exhibit; but in these cases it undergoes so considerable a degree of condensation, that it loses all the common characters

[1] Scheele dissolved even glass by boiling a small quantity of distilled water for several days in a matrass made of that material. See the Preface to his *Treatise on Air and Fire*.

of water. The water, in these instances, unites in certain definite proportions, and such compounds are known to the modern chemist by the name of *hydrates*.

Some students at Florence having provided a hollow globe of gold, filled it with water and then submitted it to the action of a very powerful press: but they were not able to produce any condensation of the fluid whatever, though the press was sufficiently powerful to occasion the water to exude through the pores of the metallic vessel in which it was inclosed [12]. Notwithstanding this, the description of an instrument invented by Mons. Abich for the compression of water will be found in the Monthly Review, vol. lxviii. p. 176.

Zimmerman states that water may be compressed so as to produce a diminution of its bulk nearly equal to 1-24th part, giving it a specific gravity even greater than that of sea water [13].

Canton long ago proved the expansibility of water; but Mr. Jacob Perkins has lately contrived an instrument which he calls a Piezometer, in which he has subjected water to a pressure of 326 atmospheres, and has succeeded in increasing its density 3.5 per cent. [14] Nature however, as has already been hinted, effects the condensation of water in many of her operations, and it will be sufficient to establish

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[12] *Essays of Natural Experiments made in the Académie del Cimento*, Waller's Translation, 4to, London 1684, page 203.

[13] *Treatise of the Elasticity of Water*. Amsterdam.

[14] *Quarterly Journal of Science*, vol. x. p. 399.

the truth of the assertion just to mention a few examples.

It is an axiom in chemical science, that bodies in acquiring condensation give out caloric [15]. Thus water always parts with caloric in the act of freezing, though it takes such a form during its crystallization as disguises the actual condensation of its parts, and occasions a diminution of its specific gravity. But water thrown upon quick lime gives out more heat than it does in the act of freezing: consequently it becomes more condensed when combined with the lime, than when it exists in the state of ice.

If a hot saturated solution of sulphate of soda be corked up in a glass bottle containing a thermometer, and then laid aside to acquire the temperature of the atmosphere, the solution will cool without the salt crystallizing. When the whole has become sufficiently cold, and the degree noted at which the mercury stands in the thermometer, if the cork be then removed to admit the atmospheric air, the salt will instantly shoot into crystals, and the mercury will rise in the thermometer several degrees. What can this rise of the thermometer be owing to, if it be not to the water parting with its caloric as it unites with the sulphuric salt and becomes condensed in the newly formed crystals?

This salt, which will preserve its figure and so-

[15] The constant rise of temperature in the atmosphere after rain, is owing to the aqueous vapour giving out caloric while it is changing into water.

lidity so long as it retains this water in its composition, will become smooth and pulverulent, when it loses the water of crystallization, by exposure to the action of the atmosphere. Those who are conversant with salts well know, that some lose the water of crystallization and effloresce, while others absorb water and deliquesce, by exposure to the atmosphere. Sulphate of soda, borate of soda, sulphite of lime, and phosphite of soda, belong to the first; and muriate of lime, muriate of magnesia, and nitrate of lime, belong to the latter of these classes.

Sometimes one salt will rob another of its water of crystallization. Thus, crystallized muriate of lime will take the water from the crystals of carbonate of soda. If both salts be inclosed in the same vessel, and yet not in contact, the carbonate of soda will fall into powder and the muriate of lime will become fluid. Should nitric acid ever be required of greater specific gravity than it can be procured by the usual methods, I suspect it might be concentrated by inclosing it in an air-tight vessel with a portion of the heaviest sulphuric acid; for this, having so determinate an affinity for water, would probably abstract more of it from the nitric acid than could be taken away by any other means.

Not only the artificial but also the natural salts, whether they be earthy, alkaline or metallic, are chiefly indebted to their respective portions of water for their transparency, for their crystalline appearance, and even in part for their solidity.

Few of the saline productions of nature are bet-

ter known than sulphate of lime, or common plaster of Paris, which when taken out of the earth is a substance very hard and compact. For the use of masons, statuaries, and some other artists, this earthy salt is broken into small pieces, and then submitted to the heat of a common oven to dissipate so much of the water of its composition as can be separated by this means. After this operation, the sulphate of lime may be easily reduced to the state of a soft impalpable powder.

When the plaster, which has been thus prepared, is to be used, the workman, in order to give it its original solidity, mixes it with a certain portion of water, and then pours it hastily into moulds, to form statues, busts, cornices, or other ornamental work for which it is generally employed. In this instance the dried plaster has such an affinity for water and a capacity to regain what it had lost, that it instantly attracts and condenses a very considerable quantity, and the whole becomes changed into one entire and very compact mass [16].

Pure alumina has a similar affinity for water, and the union is so intimate that it is almost impossible ever to separate the water with which it has been united. Saussure, who made experiments on this subject, declares that this earth has so powerful an attraction for water, that it will retain a tenth of its weight of that fluid, even though it be submitted to a heat that will fuse iron.

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[16] See Essay on Earthenware, vol. ii. p. 118.

Potash after having been submitted to a red heat is found to retain more than 13 per cent., and soda nearly 19 per cent., of water [17]. According to the analysis of D'Arcet, the proportion of water is even greater than this [18].

Seeing then that water has so great an affinity for many bodies, and that it imparts transparency to one and hardness to another, it is surely worth while to examine whether it may not fulfill an important office in some mechanical and manufacturing processes in which its operation has been least suspected.

If a perfectly compact crucible be well filled with dry chalk, and then submitted to the strongest heat that is usually raised in a common fire-place, it will be extremely difficult, if not impossible, to convert the whole of the chalk into lime. But if a hole be perforated in the bottom of the crucible, and this fixed in a situation where a current of aqueous vapour, or atmospheric air, can freely pass through it, the carbonic acid will be separated, and the lime completely formed, in less time and with less heat than it could have been effected at without such an accession. The water aids the separation of the carbonic acid, and enables it to pass off in the form of gas. This fact was first communicated to me by Mr. Dalton of Manchester; and my own observations have since confirmed the truth of his statement.

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[17] Berard in *Annales de Chimie*, tome lxxii. p. 96.
[18] *Annales de Chimie*, tome lxviii. p. 175—190.

Our common lime kilns are all built with an opening at the bottom, for the removal of the lime when burnt. This allows of a constant current of atmospheric air through the whole mass of stone, and consequently a considerable portion of water is conveyed to it during the whole progress of the operation. I would therefore suggest to the burners of lime, that it may be worth while, whenever they draw the contents of a kiln not sufficiently burnt, (which often happens,) to notice whether the atmosphere had not been in an unusually dry state at that period, and whether the imperfection of the lime should not have been ascribed rather to this than any other cause.

Should this be found to be the case, the inconvenience might be obviated by placing a broad vessel of water at the mouth of each kiln; because the heat of the kiln would occasion a constant evaporation from its surface, and the current of air which sets through the kiln would convey the aqueous vapour to every part.

In like manner, there is reason to believe that quick lime would not combine with carbonic acid, however long it might be exposed to its action, provided water were not present; and that the mortar or cement employed in buildings would never acquire the hardness of which it is capable, were it not for the gradual absorption of the water of the atmosphere.

I have been told that the Earl of Stanhope has formed an establishment for burning lime on some

new principle, and that he furnishes it in a state of greater purity than it can be had elsewhere.

Vegetable fermentation cannot take place without water; and I suspect that the excellence of wine and all other fermented liquors depends in a great measure on the proportion which the water bears to that of the sugar and the mucilage. The perfection of the process of malting, as is well known to all good maltsters, depends in a great measure on the couch being properly sprinkled with water. In forming solutions of the metals in the muriatic and some other acids, the water becomes decomposed in proportion as its oxygen is required to oxidize the metal, and its hydrogen escapes through the fluid in the form of gas. This in some degree accounts for the great loss of weight which is always experienced in making the solutions of tin and other metals.

Here it may perhaps not be amiss to advert to a circumstance which may involve the safety of some individuals. What I allude to is this; that those persons who are in the habit of preparing large quantities of muriate of tin, are perpetually liable to misfortunes by an explosion of the hydrogen gas which escapes during the process. Very lately, a friend of mine in the country was much cut in the face and otherwise injured by the fragments of an apparatus in which this operation was going on, and which burst with a tremendous report, in consequence of a lighted candle having been incautiously brought too near it.

Though water is decomposed and a loss of weight is sustained in many chemical operations, water, on the contrary, is often *produced* in certain cases of combustion, where the presence of this fluid is least suspected; and this may influence the results of many operations in a way that is quite inexplicable to those who are unacquainted with the principles of chemistry. Spirits of wine, oils, wax, tallow, and many other substances, always produce water during their combustion. If a cold glass vessel be inverted over the flame of burning alcohol, water may be collected that is perfectly free from taste or smell, and in every respect like distilled water. One pound of alcohol will produce eighteen ounces of water [19].

The PURITY of the water that is employed in some of our manufactures is an object of the most material consequence. A few instances may easily be adduced to substantiate the truth of this assertion.

In the processes of bleaching, dyeing, and calico-printing; in those of refining sugar, of brewing malt liquors; in the manufacture of paper, and in many others which might be enumerated; the quality of the article is much influenced by the nature of the water which has been employed in its production.

More than two thousand years ago Hippocrates wrote expressly on the difference observable in waters. Celsus gave directions for examining the

[19] This subject is further elucidated in the 12th chapter of *The Chemical Catechism*.

specific gravity of water[20], and Pliny attempted to direct his readers how to distinguish the salubrious from that which is unwholesome. But, till the time of Boyle or towards the end of the seventeenth century, no means had been devised of analysing water, or of pronouncing with certainty on its nature and properties.

There is a letter still extant from Synesius, a Christian bishop of the fifth century, to the female philosopher Hypatia, under whom he had formerly studied, in which he complains of being ill; says that he wishes to use a *hydroscopium*, and requests that she would cause one to be constructed for him. "It is a cylindrical tube," he adds, "of the size of a reed or pipe. A line is drawn upon it lengthwise, which is intersected by others, and these point out the weight of water." It is probable that the bishop was in an infirm state, that his physicians had ordered him to drink none but pure water, and that the instrument he wanted was one similar to our hydrometer for the purpose of examining the weight of different waters, in order to ascertain which would be best for his use.

Those which are generally known by the appellation of *hard* waters, hold certain salts in solution, and are unfit for private use as well as for manufacturing processes. Frequently, however, according to the remark of Bergman, the sum of all the saline substances dissolved in a mineral water does not ex-

[20] Celsus *De Medicina*, lib ii. cap. 18.

ceed a six-thousandth part of its weight, and yet may be composed of six or eight different substances. Mr. Dalton asserts, from the result of his own experiments, that the hardest spring water seldom contains so much as one-thousandth part of its weight of any foreign body in solution [21].

Nature, who in her inexhaustible bounty gives us distilled water from heaven, has so ordained it, that there are few districts of much extent where spring water may not also be found, which is sufficiently pure for most purposes either of manufacture or domestic economy [22].

It may here be remarked, that in sinking wells it is important to line them with free-stone, and not with bricks as is usual, because most of the bricks which are made in this country have the property of hardening the water; whereas the stone has not this effect.

Nearly seventy years ago Dr. Home explained why hard water is injurious to dyers and bleachers. It is related by him that Mr. Samuel Hart, who was a celebrated bleacher in the middle of the last century, was about to establish a new bleach-field in a particular place, which seemed favourable for his purpose on account of the appearance of the

[21] *New System of Chemical Philosophy*, p. 271.

[22] This assertion is somewhat contradicted by Dr. Plot in his History of Staffordshire, who relates a case of a well which was sunk in that county to the depth of 2,600 feet, without meeting with water: but this was a rare instance. See *Journ. des Scav.* 1680, p. 14.

water and the abundance of the supply; but when he came to examine it by some of the best chemical means then known, it was found so impure, that he deemed it expedient to form his intended establishment on another spot[93]. Most of our spring water contains common salt, with carbonate and muriate of lime; but it is the *sulphate* of lime which constitutes what we call *hard* water.

In coal districts, where the coal occurs near the surface of the ground, the brooks and rivers in the neighbourhood are often contaminated by the result of the decomposition of the sulphuret of iron called martial pyrites, which is washed into them by the rains. I know of one instance in Yorkshire where an establishment for scouring and dyeing woollen yarn must have been entirely broken up from this cause alone, if the proprietors had not found the means of leading a current of water from an adjacent spring for the supply of the manufactory.

They had been in the habit of using the water from the river Calder, which has constantly a portion of the coal-pit water running into it; and in the summer months, or in very dry seasons when there is less good water to dilute the coal-pit stream, the Calder water, for most of the purposes for which a dyer requires it, is rendered nearly useless. This had long been a cause of vexation and inconvenience to these individuals, when the bursting of one

[93] *Experiments on Bleaching*, by Dr. Home, 8vo, Edinburgh 1756, p. 281—288.

of the worn-out coal-pits so inundated the bed of the Calder with the solution of sulphate of iron, that its water became totally unfit for their purpose; and this induced them to resolve upon incurring the expense of supplying themselves from another source. The establishment of which I have been speaking is not a large one, and yet the proprietors have repeatedly assured me that the consumption of soap in scouring their woollen yarn is, in consequence of the softness of the present water, so much diminished as to occasion a saving to them of more than fifty pounds per annum. I am also acquainted with some gentlemen in the north of Scotland who are proprietors of a very extensive establishment for bleaching and printing calicoes, and who for many years had been in the habit of bleaching with the water from the river Don, but had long been dissatisfied with the uncertainty that attended all their processes, and which they could ascribe to nothing but the impurity of the water.

These gentlemen possessing much chemical knowledge, at length came to the determination of analysing the waters of all the neighbouring springs, and then to bleach a parcel of goods with the utmost care in that which appeared to possess the greatest purity. The result answered their most sanguine expectations. Less alkali was required in the process, and the difference in the appearance of the finished goods was very considerable and obvious.

When the superiority of this spring of water was

thus ascertained, the individuals above referred to were at the expense of conducting it in pipes for three miles through their own estate, taking care to divert the waters of those springs which contained iron into another channel: the good water was made to empty itself into one vast cistern, capable of containing many thousand gallons, made with slabs of Scotch granite put together with Roman cement, and securely puddled on the outside with clay. In this reservoir there are some contrivances for the receiving of the water and for its delivery to the works, which I intend to describe in another part of this Essay. The construction of this reservoir, and the expense of bringing the water from so great a distance, amounted to more than two thousand pounds; but the advantages accruing to the manufactory from the possession of this excellent water have been so great and important, that some of the proprietors have informed me that they have no cause to regret the amount of the expenditure. Independently of an elucidation of our present subject, I consider this to be a striking instance, among many others which are daily occurring, of the benefit derived to the arts from the cultivation of chemical science.

I may here remark, that in the conveyance of water from a considerable distance it is of great importance to ascertain how much of that fluid a pipe of a given bore will deliver in a certain time; because iron pipes are apt to oxidize on the inside and contaminate the water, unless they be kept

nearly full; whereas, when they are not large enough to take off the quantity which is thrown into them, they are liable to burst [24].

To those persons who have no idea that difference of water can produce such important effects in bleaching, I would earnestly recommend the repetition of the following easy experiment. Take half a pint of *distilled* water—drop into it a single drop of the tincture of galls and an equal quantity of solution of sulphate of iron, and let the whole be stirred with a glass rod. On observing the effect which this minute quantity of these reagents has produced in the water, it will be perceived that only a very slight change of colour has been occasioned by it; whereas, if an equal quantity of *spring* water be added to the former mixture, the whole will immediately become black.

In some processes of calico-printing the perfection of the water is of great moment, and to the dyer of fine colours pure water is indispensable; but the case which has just been related refers chiefly to the bleaching of linen and calicoes, which can never take a perfect white if the water employed be contaminated with saline substances or with minerals of a metallic nature. The term *pure* water is not intended to be taken in the strictest sense of the

[24] Persons desirous of solving this problem may consult the Second Book of Newton's *Principia*; Belidor's *Architecture Hydraulique*; Robertson in the *Philosophical Transactions* for 1758; or a *Dissertation on the Force of Running Water*, in a volume of "*Dissertations on Rural Subjects*, 8vo, printed for Robinson, London, 1775."

words, for rain water itself is not absolutely pure. Such water, when collected by spouts from the tops of buildings, is found to have dissolved a portion of selenite from the tiles; and if caught in an open field it is generally contaminated by the heterogeneous particles which are always floating in the atmosphere. For the purposes of chemical analysis nothing can be depended upon but distilled water. The ancient chemists, however, always preferred rain water for all their processes.

In reference to bleaching it may be worth while to mention, that there are many manufacturing districts in this kingdom which are situated near to peat mosses, some of which are of considerable extent; and that all such places are very improper for the establishment of bleach-works, because at flood time these marshes pour into the adjacent rivers large quantities of iron in a state of solution which contaminate the waters for many miles.

A remarkable instance of the impurity of spring water occurs in Portugal. In several parts of that kingdom the waters are so hard that for many purposes they are entirely useless. The following is a case of peculiar difficulty.

The wool which is produced in Spain and Portugal contains so much animal oil and other impurities, that when scoured it will not produce more than half its original weight, and in some cases three pounds will not yield more than one pound of clean wool fit for the English market. As these wools pay a considerable duty to the Spanish and

Portuguese Governments on their exportation, the Spaniard finds it his interest to clean them thoroughly before they are shipped for sale to Britain or elsewhere; but in Portugal the merchant cannot avail himself of this expedient, because the waters of that country are unfit for the operation.

I know a merchant who has an establishment in Portugal for the purchase of wool and for the sale of English woollen cloth, and he informs me that he is under the necessity of shipping very large parcels of wool in its original state, which occasions a great reduction of profit, merely for want of the means of having this wool properly washed in Portugal.

I suggested to this gentleman the scheme of collecting urine for the purpose. I stated that this fluid, when it becomes stale, produces a large portion of volatile alkali, and that the addition of a small quantity of quick lime would remove its offensive smell and render it fit for any operation of washing or scouring: and that it would, if added in a small proportion to hard water, render such water soft and fit for any detersive process whatever. But he assured me that this could not be done; for that the inhabitants of this country have so much pride, and so little idea of the importance of manufactures, or of any economical improvements, that it would be impossible, by any reward, to induce the poorest man in the country to engage in such an occupation.

The ancient Romans had recourse to urine for scouring woollen cloths. It is, indeed, probable

that it was more largely employed by them for this purpose than even by the moderns, from the circumstance of the Emperor Vespasian having laid a tax upon it, which remained long in force, and continued to be exacted for more than 200 years[25]. The scourers of old were so careful in the collection of this article, that the Government extorted the payment of the tax even from those who kept cattle, *vectigal pro urina jumentorum*. Athanasius, however, although he was the most frugal and economical of all the Roman emperors, relieved his people from this odious impost[26].

It is probable that the ancients had no conception of the method above mentioned, of sweetening stale urine, because it appears that the scourers at Rome were all obliged to reside in the most unfrequented parts of the city[27].

The fullers of cloth and scourers of wool in ancient Rome considered this article to be so important and necessary for the support of their respective occupations, that they contrived a variety of methods of collecting it, all which may be seen in the xxviiith book of Pliny's Natural History.

In returning from this digression to the reconsideration of the nature of spring and river water, it may be observed that the instance which has been adduced of the difficulty there is in cleansing wool

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[25] Suetonius's *Life of Vespasian*, § 23.

[26] Gibbon, vol. vii. octavo edit. p. 101. Beckmann, vol. iii. page 251.

[27] Pliny, lib. xxviii. § 6 &c.

in Portugal, shows in a striking manner that a cheap and easy method of purifying the spring waters of that country must be a desideratum of great national importance.

It is my more immediate business, however, to direct my attention to the improvement of the trade and manufactures of the British dominions; and to this end I shall proceed to give some directions for the choice of spring water, and shall endeavour to point out some of the best means which can be employed to purify it for the use of manufacturers or for domestic purposes, in those situations where one kind of water, and that only, can be easily obtained in sufficient quantity.

It would extend this Essay to too great a length to lay down rules for the complete analysis of all the various kinds of water which these islands produce, especially as Dr. Kirwan and others have written expressly on this branch of the subject: but some directions for ascertaining the *comparative* goodness of water may be of especial service to the manufacturing part of the community, and this may perhaps be done without occupying much room, or occasioning fatigue to the general reader; and it may be observed, as we proceed, that it is of consequence also to the agriculturist to be able, in some measure, to analyse water; for those who have studied the subject of irrigation, and carefully observed its effects, have found that the benefits resulting from this practice very much depend

upon the nature of the water which is employed[28]. Even horses will refuse hard water when they have long been accustomed to soft[29].

In examining water, the first thing to be attended to is its specific gravity[30]; and I conclude, from a remark which is made by Pliny, that this method of trying the purity of water was known to his contemporaries. "Good water," says he, "ought to have neither taste nor odour at all. Some there be who judge of their wholesomeness by the balance, and they keep weighing and poizing of waters one against another[31]."

There can be no doubt of the importance of attending to the specific gravity of spring or river water, as this alone will often lead to a knowledge of its nature and purity; for those waters which are the most unfit for culinary purposes, or for the use of manufacturers, are generally specifically heavier in proportion to their impurity. If, therefore, a sample of water should prove to be of the same weight, or but a little heavier than rain or distilled water, and devoid of colour, taste, and smell, it may generally be pronounced to be fit for most purposes, either of the arts or of domestic economy.

Should it be intended to prosecute the examination further, it will be an easy experiment to put a

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[28] See Boswell's *Treatise on Watering Meadows*, p. 10, &c.

[29] Baynard *on Cold Bathing*, 8vo, London, 1732, p. 299.

[30] Directions for taking the specific gravity of fluids will be found in the Third Essay, vol. i. p. 199—238.

[31] Holland's *Pliny*, book xxxi. chap. 3.

thin slice or two of white soap into a clean glass tumbler, and then to pour half a pint of the water over it, which is required to be examined. When this has stood undisturbed for half an hour, the appearance of the water will be a good evidence of its relative purity, as it will then be seen whether it be what is called *hard*, and consequently impure, water, or otherwise. The Spanish soap, usually known by the name of Castile soap, an article sold by the chemists, and which is made of soda and oil of olives or oil of almonds, is the best; but good English white soap will generally be found very suitable for the purpose. A little Venice soap dissolved in alcohol will form a test by which the comparative hardness of water may be determined in an instant.

Water which holds any of the earths in solution, or any of the metallic or earthy salts, has the property of decomposing soap, while pure water will completely dissolve it. In the former case the alkali separates, and the earth combines with the oil or the tallow; in the latter, the soap is decomposed by double affinity, the acid uniting with the alkali, while the earth or the metal combines with the oil, and forms an earthy or metallic soap. In both instances the new compound is insoluble, which occasions the coagulation above mentioned. It may therefore be said that in this experiment, if the fluid present a smooth equable appearance, without any white flakes or curdly particles interspersed among it, the water may be considered good; otherwise it

must be deemed hard, and this in proportion to the quantity of the white insoluble matter which is perceived in it.

One of the substances most commonly found in water, and the most injurious to manufacturers, is iron. To discover the presence of iron, prussiate of potash, or tincture of galls, may be employed. The first of these reagents will occasion a *blue* colour in the water if iron be present; the tincture of galls will produce at first a purple and then a *black* tinge.

These short directions will be enough to enable manufacturers in general to ascertain whether the water in their vicinity has a degree of purity sufficient for their respective purposes: and wherever a complete analysis is required, recourse must be had to Kirwan [33], or to some other chemical writer who has given the proper directions for conducting such an examination. In pursuing this inquiry, "Bergman's Physical and Chemical Essays," "Dr. Henry's Elements of Experimental Chemistry," "Dr Thomson's and Murray's Systems of Chemistry," and the fourth volume of "Fourcroy's General System of Chemical Knowledge," may all be read with advantage.

It may however be worth while to embrace this opportunity of showing that brooks, rivers, and springs, are liable to be contaminated with a variety

[33] See *An Essay on the Analysis of Mineral Waters*, by Richard Kirwan, Esq. F.R.S. 8vo. London, 1799.

of impurities, all of which may be detected by chemical reagents in the following order. Other substances however, besides those which are enumerated in the subjoined list, have been found in natural waters; but as these are such as are chiefly to be expected, it has not been thought necessary to enlarge the catalogue.

A tabular View of those Reagents which are usually employed to detect the Impurities of Spring and River Water.

Oxalic acid, or any of the oxalates, ...	Will discover	Lime, or either of the salts of lime.
Infusion of litmus, or syrup of violets, or infusion of red-cabbage leaves, ...	....	Uncombined acids.
The same, slightly reddened by vinegar; or turmeric paper, ...	....	Pure alkalies and pure earths.
Muriate of platinum	....	Potash, or the salts of potash.
Acidulous nitrate of silver	....	Muriatic acid, or the muriatic salts.
Muriate of barytes	....	Sulphuric acid, or the sulphuric salts.
Lime water	....	Carbonic acid, magnesia and alumina.
Acetate of lead	....	Sulphuretted hydrogen.
Muriate of lime	....	Carbonated alkalies.
Polished iron or steel	....	Sulphate of copper.
Phosphate of soda[34]	....	Magnesia.
Sulphuret of potash	....	Lead.

[34] This of test magnesia was first recommended by Dr. Wollaston. For the method of managing it, see Dr. Henry's *Chemistry*, vol. ii. page 431.

The manufacturer having ascertained, by means of one or more of these tests, that the water upon his premises is not fit for his purpose, it then becomes a question of prudence whether he shall attempt to purify this water, or search for some other source from whence he may draw such as is naturally pure enough for the use of his manufactory.

It is probable that in many parts of this kingdom such a search would be crowned with success. Dr. Home has stated that "the water of the Edinburgh wells not only thoroughly dissolves soap, and retains its transparency when salt of tartar is mixed with it, but even shows no lactescency when nitrate of mercury is dropped in[31]."

The means which might be adopted for the purification of water are various, and nature herself makes use of several of them in order to present us with this article of the first necessity, in a state of sufficient perfection for all the common purposes of life; and among other operations she chiefly employs those of distillation and filtration.

The most contaminated waters on the face of the earth are daily purified by the action of the sun's beams, which separate the limpid particles from the polluted mass and elevate them into clouds, from whence they are distilled in showers of rain, hail or snow. The hills and mountains of the globe also perform a similar office, by allowing the waters in their vicinity to percolate through them,

[31] Home's *Experiments on Bleaching*, p. 252.

and hence are presented to us in various degrees of purity, according to the nature of the different strata of earths or minerals through which they have permeated[36].

The former of these methods is successfully imitated whenever we prepare distilled water; but this is a process which is too expensive for most manufacturing purposes. The latter, that of percolation, may be copied by art on a large scale; and the water which is thus purified, may be employed for some uses with considerable advantage. Here, however, we can only strain off some common contingent matters without changing the soluble principles; while nature, by her superior powers, can even decompose what is injurious, and cause the impurities to subside or separate entirely.

I have often thought that at those large works where a steam-engine is constantly employed, a sufficient quantity of distilled water for all the nicer purposes might be collected from the waste steam, if a proper receptacle were contrived for condensing it. The advantages that would accrue from such an arrangement to the dyer of rich colours, and to the printer of fine calicoes, are incalculable.

Here it may be observed, that when fresh water becomes scarce at sea, excellent soft water may be readily procured for the use of the ship's crew, by distilling the salt water with some wood-ashes or

[36] Those springs which arise out of limestone rocks are generally hard; whereas, the waters which have filtrated through a long extent of gravel are often extremely soft.

other vegetable alkali. A memoir expressly on this subject may be seen in the Philosophical Transactions for the year 1758.

I had some time since an opportunity of examining the plan of an extensive reservoir, at that time making by a very ingenious manufacturer for the sole purpose of filtrating water, and which was of the enormous size of sixty yards long and forty yards wide. This vast receptacle was formed near the side of a river, and sunk several feet below the surface of the adjacent ground. When the soil had been carried out to a depth which was thought sufficient, several broad trenches were sunk a foot or two deeper than the main bottom, and these were filled with boulder stones or very large pebbles, to prevent the possibility of these passages for the water from ever being filled up. Over these, and over the whole bottom of the reservoir, a large bed of gravel was laid, and then the remainder of the pit was filled up with fine screened sand.

In using this reservoir, it was the intention of the proprietors to fill it with water, by means of a pump fixed within the river, and worked by the steam-engine; and it was considered that the water would be purified in its passage, while pervading the sand and gravel; that the trenches below would be constantly full of pure water, and that the manufactory would be furnished with a perpetual and transparent limpid stream[37].

[37] The waters of the Seine are purified somewhat in this way for the use of the inhabitants of Paris. The Egyptians purify their river water with alum.

I have not yet heard of the success of this project, but I have no doubt of its answering fully all the expectations of the projectors: though it must be recollected by those who may be desirous of practising this mode of purification, that it is only capable of separating the argillaceous earth, or such impurities as are merely suspended in the water, and not any of the earths or salts which are chemically combined or dissolved in it.

In making a reservoir of this kind, there are many circumstances to be attended to, which may appear insignificant in themselves, and yet the neglect of one of them may be sufficient to defeat the whole of the intention. Thus, if precautions are not taken, worms will burrow through the bottom and sides of such receptacles, and by the passages thus formed will divert the water from the bed of the filtrating materials into other channels.

To guard against this, it is necessary, when the bed of the reservoir has been well puddled with clay, to lay a thin coat of coal-ashes over it, and to secure the sides in the same manner; it having been found that this will effectually prevent these small animals from penetrating.

It is also necessary, when the gutters are filled with the boulder stones, to cover them with long straw to prevent the gravel from running among them. The same expedient should likewise be adopted afterwards, when all the gravel has been laid on, to prevent the sand which is then to be spread over from running among it; but where a

large sum is to be expended in one of these reservoirs, I would earnestly recommend that the advice of a person should be taken who has had experience in these matters.

In pursuing the subject of purifying waters for the use of our respective manufactories, I would remark that it is right to encourage the growth of weeds, and the different kinds of aquatic vegetables, in all large reservoirs of water belonging to such establishments, as they have the faculty of very materially purifying the water in which they grow. Some very interesting dissertations on this subject will be found in Priestley's Experiments on Air, &c. under the article "Green vegetable matter floating on stagnant water[38]." Hard waters have the property of retarding animal and vegetable putrefaction; but when putrefaction does take place in such waters, it alters their quality, and they become entirely soft[39]. The antiseptic quality of hard waters was known to Celsus, an eminent physician of the first century. "If this were the proper place," says Dr. Home, "we could easily account for all the bad effects of hard water on the human body; and show that by the separation of the acid from the terrestrial base, which will happen in the body, several diseases must arise. These unwholesome effects of hard water may be prevented by previously mixing

[38] See the 5th vol. of Priestley's *Experiments on Air*, being the second of his *Observations on Natural Philosophy*. Birmingham, octavo, 1781, p. 16—63.

[39] See Dr. Home's *Treatise on Bleaching*, p. 229.

alkaline salts with it [40]. Some waters are purified sufficiently for manufacturing purposes, merely by an exposure to the action of the atmosphere. Thus, some chalybeate waters deposit the iron in a thin pellicle on their surface, owing to its becoming insoluble by its absorption of oxygen. I know also of an instance at a print work, where a very shallow stream of water, which ran through the works, was found too impure for many of their purposes; but when the same rivulet had passed these premises, and had reached another work which belonged to the same proprietors, situated at a considerable distance from the former, it was always found to be fit for most of their operations.

A large portion of the spring water of this country is rendered unfit for many manufacturing purposes by the selenite which is contained in it; but surely such water might, at a trifling expense, be sufficiently purified for most occasions, unless the consumption of it were so large, as that this circumstance alone would create an insurmountable objection.

Water contaminated by selenite (sulphate of lime) may be rendered pure by means of a solution of barytes [41], an article which may be prepared at a comparatively small expense, and would be of incalculable advantage in many processes of art. I

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[40] Home's *Experiments*, page 295.

[41] For the method of keeping barytes in a state of purity, see Essay V. vol. i. page 344.

have here in view the preparation of barytic earth from the common Derbyshire cauk, as described in vol. i. p. 361, and which I conceive would be sufficiently pure for this purpose. All that would be necessary would be to drop the solution of that earth, by degrees, and in small portions, into the water intended to be purified, till it occasions no further precipitate. In this way pure water might at any time be had for chemical experiments; for, if too much of the barytic solution should by accident be employed, the carbonic acid inherent in the water, or that of the atmosphere, will soon combine with it, and occasion it to precipitate along with the decomposed selenite. I cannot however recommend the water purified in this way to be used for domestic purposes, as the barytic earth is poisonous.

When barytes is not to be had, and in all cases where it would be improper to employ that earth, such water may be rendered soft, though not perfectly pure, by the addition of a small quantity of the sub-carbonate of potash (the pearlash of the shops) or a few of the crystals of soda. Either of these alkalies will combine with the sulphuric acid and precipitate the lime; and when a sufficient time has been allowed for the deposit to be formed, such water will be fit for every culinary, and for most manufacturing or domestic purposes. Where there is the convenience of proper reservoirs, this is a most effectual way of softening hard waters; and for every purpose of washing or scouring, the effect may be produced at a still cheaper rate by means of

stale urine. This might be sweetened as directed at page 377, and then poured into the water by degrees till the object was completely attained.

The great desideratum, however, with bleachers, dyers, and calico-printers, is to discover a cheap method of precipitating iron from any of those waters in which it may be dissolved, as the salts of iron held in solution by the waters of brooks and rivers are often very injurious in the practice of those arts.

The solvent of the iron in these cases is often, if not generally, sulphuric acid; therefore, in those situations where it is convenient to have cisterns or other reservoirs for the water, the solution of pure barytes might be employed with equal effect. The barytic earth would immediately seize the sulphuric acid and precipitate it; and the iron, having thus lost its solvent, would fall also. This precipitation of these impurities will commence immediately upon the application of the barytes: and when the whole has remained a few hours undisturbed, the water will be fit for use. It will be obvious that care must be taken to add no more of the barytic solution than is absolutely necessary to throw down the iron; otherwise, when the iron has been separated, the water will be found to be contaminated by the reagent itself. In Scotland the poor get up their own household linen, and bleach it themselves in their own gardens. Dr. Home relates the case of a poor woman who watered some webs she was bleaching, from a spring near her own house. To

her great surprise, they became redder and redder every day. She attributed it to witchcraft; imputed the crime to the neighbour she hated most; and sold the cloths for a trifle. The Doctor afterwards analysed the water, and found it contained iron. To discover whether the iron be held in solution by the sulphuric, the muriatic, or the carbonic acid, treat it with a small quantity of the nitrate of barytes. If this throws down a yellow precipitate, and the water loses its brackish taste, it may be concluded that the iron is dissolved by the former of these acids; but if these effects are not produced, some other acid must be considered to be the solvent. Boiling the water will show whether it is carbonic acid that holds it in solution.

In cases where no danger would arise from a small portion of lime, waters may, indeed, be divested of iron merely by the addition of a little of this earth in powder [48]. It would be proper to use *fresh burnt* lime; and should more of this be employed than is necessary to separate the iron, the superabundant quantity may be precipitated by allowing it time to absorb carbonic acid from the atmosphere. And where time could not be spared for the completion of this process, the judicious application of a very small quantity of sulphuric acid would separate the whole in the course of twenty-

[48] Pliny speaks of purifying brackish water with chalk, which is a subcarbonate of lime. See lib. xxiv. cap. 1.

four hours, and leave the mass of water in a state of purity fit for any purpose either of manufacture or domestic economy.

To accomplish this on a large scale it will be necessary to have two reservoirs, which might adjoin each other, and then the impurities would be subsiding in one, and its water becoming fit for use by the time the water of the other was expended.

From repeated observations I am convinced that large sums of money have been needlessly spent in the purchase of expensive cements for making underground water-cisterns, and that brick walls properly built and well puddled with clay are fully sufficient for the purpose. I have myself more than once constructed a large underground cistern in this manner, which held perfectly tight for several years, and probably would last at least a century. A detail of the methods which I pursued would occupy more room than I can spare; but I refer the reader to a work where he may obtain an abundance of useful information on this subject, viz. Switzer's System of Hydrostatics, in 2 vols. quarto, London 1729, vol. i. p. 129, illustrated with a copper-plate engraving of the sections of several reservoirs of different forms and dimensions. Vitruvius says that the ancients constructed their underground cisterns with a composition made of lime-mortar, sand and pebbles, well beaten together [45].

The reservoir mentioned at page 374, and formed

[45] Vitruv. *de Architectura*, lib. viii. cap. 6.

for the use of a large print work and bleaching establishment in the north of Scotland, was constructed with a different intention. This was designed chiefly to form a receptacle for purer water than that which they had been accustomed to use, and also that the water to be employed in the manufactory should be constantly exposed to the purifying influence of the atmosphere. It were well if all our manufacturers were equally circumspect.—In China there is a certain lake surrounded with villages and full of inhabitants, who are absolutely drawn thither by a persuasion that the silk washed in that lake derives from thence a lustre not to be obtained in any other way[44].

Since the former part of this Essay was written, I have been favoured, by one of the proprietors of the reservoir just alluded to, with a particular account of its construction, and also of the expedients they adopted in order to procure a regular supply of water, and have it delivered to the works in a state of sufficient purity for all their purposes.

The reservoir, which is formed with large slabs of Scotch granite, put together with Parker's cement, is fifty feet long, thirty feet wide, and ten feet deep. This receptacle is filled with water conveyed thither by iron pipes, from a spring at three miles distance, the water of this spring having been found to be the purest of any in the neighbourhood.

It is observable that the reservoir is very shallow

[44] Du Halde, *Description de l'Empire de la Chine*, tom. i. p. 127.

in comparison with its extent, and this form was given to it in order that a large surface of water should be constantly exposed to the atmosphere. The design of this will be immediately perceived, when it is understood that this water passes through a bed of lime-stone, and that when it is delivered at the reservoir it holds a portion of that earth in solution. For by this exposure of it to the air, it loses that excess of carbonic acid which dissolved the carbonate of lime, and then this earth from its natural insolubility separates, and falls to the bottom of the cistern. Mr. Cavendish determined that 1200 grains of water impregnated with fixed air and yet not fully aërated, could hold in solution one grain of chalk. Berthollet in Mém. Paris. 1780, p. 127, states, that 500 grains of water *fully* impregnated with fixed air can hold one grain of aërated lime; and Kirwan has shown, that when the proportion of water to that of chalk is very considerable, for instance, as 12,000 to one, then the weight of fixed air necessary to keep the lime in solution is about half its weight when aërated; and if the proportion of water be still more considerable, a still smaller weight of fixed air is required. He also states, that if the weight of the carbonic acid which is united to water exceeds that of the chalk, it will dissolve it let its volume with respect to that of the water be ever so small [45]. It having, however, been foreseen that the precipitate of calcareous

[45] Kirwan *on the Analysis of Mineral Water*, page 20.

earth would constantly accumulate in this reservoir, and soon become considerable, the water from the pipe of conveyance is not allowed to rush in at the surface, but is delivered into a capacious wooden trough which goes nearly to the bottom of the cistern. By this contrivance no water can enter but at the bottom, and there it becomes distributed, without occasioning the least disturbance to the surface; which is a point of considerable consequence, especially as the manufactory is supplied, as will be explained hereafter, only from the uppermost stratum.

At first an inconvenience arose from the circumstance of conveying the water from the spring in *iron* pipes, as those parts which were not constantly covered with water became oxidized by the action of the atmosphere, and in consequence of this the contents of the reservoir were soon contaminated by iron in a considerable degree. However, by adapting a stop-cock, and otherwise preventing the circulation of air within the pipes, the iron is now preserved from solution, and the complaint of having a chalybeate water is no more heard.

It being a main object with the proprietors of this manufactory to improve the water by exposing it to the action of the air, in the way already noted, they conceived that the upper stratum must always be the purest, and therefore they determined never to draw any off for the use either of bleaching or calico printing but from the surface, and this they effect by the following expedient.

A copper pipe, with a large stop-cock attached

to it, is firmly fixed in one side of the reservoir, at a convenient distance from the bottom; and at that end of the pipe which is within the water, a flexible tube of leather about 18 inches long is affixed and supported upon rings of copper, sewed withinside to prevent the pressure of the water from occasioning the leather to collapse. It will be obvious that where the water is not to be consumed close to the reservoir, a series of pipes, instead of the stop-cock, might be attached to the flexible tube, and thus the water might be conveyed to any distance. To the other end of this flexible pipe, one of copper is fixed, with a rose-head, as it is called, at the other extremity; that is, this end of the pipe is pierced full of small holes for the entrance of the water, and this is surmounted by a large air ball made of thin copper so as to be capable of swimming in water. By this contrivance, whatever depth of water there may be in the reservoir, one half of the air ball is always out of the water, as shown in the drawing[46], for the flexible tube allows it to rise or fall with the water, and consequently the perforated end of the copper pipe at which the water enters is never more than an inch or two beneath the surface, so that none but the very purest portion of water within the reservoir can ever be drawn off for use.

It appears to me, that this is a very simple and effectual contrivance for obtaining good water; and the improvements which have obviously appeared in

[46] See the Plate prefixed to this Essay, fig. 4.

several of the processes of this establishment justify my recommendation of the scheme, and induce me to say that it is my decided opinion that a similar one should be adopted not only at other works in Scotland, but throughout the British dominions by all those bleachers or printers whose situations will admit of it.

Dr. Campbell, when treating of the waters of Great Britain, makes an observation much to our purpose: "Nature," says he, "is said to be a *mother* to some people and a *step-dame* to others; but the real truth is, that Providence is kind alike to all, and it is industry only that makes a difference between nations; for those who contemplate her gifts, and study how to make use of them, very rarely fail of finding their pains rewarded, even beyond their expectations[47]."

But to return to our subject. The necessity there is of pure water for the use of the bleacher has been fully explained in the foregoing Essay; but to the printer of fine calicoes it is, perhaps, of still greater importance. Such water must be used in every process from the first to the last for the *light coloured* prints; for a single operation either of dunging, washing or dyeing such pieces in common water, would spoil the delicacy of the grounds, and decidedly impair the beauty of the goods.

Bleachers are not always aware of the loss they sustain, in the extra consumption of potash, by the

[47] *Political Survey of Britain*, quarto, vol. i. p. 109.

use of hard water; nor are they apprised that the saline substances which render the water hard, must either be all neutralized or decomposed at the expense of the alkali, before such water can be rendered efficient in any of their processes. A table of the comparative power of various substances with regard to softening and hardening of water, will be found in the work of Dr. Home already quoted, page 249. Likewise several curious experiments on the effects of different waters in sundry culinary operations, pages 288—298.

Brewers of malt-liquors labour under as great an inconvenience from the use of hard water; for it is well known that the largest portion of extractive matter cannot be drawn or separated from the vegetable substance by means of such water. The annual profit of a brewer must therefore in a great measure depend upon the purity of the water he employs, as well as on the goodness of his malt[48].

To the grower of flax for the operation of steeping, *soft* water is of the utmost consequence. In such water the process usually goes on with regularity and safety, whereas in water that has a considerable degree of hardness, the flax may lie month after month until its texture be injured, and still the ligneous matter will not be properly separated. The intention of steeping is to loosen the *hark* or bark of the flax from the *bun* or woody part of the

[48] See the Letters on Brewing, in the *Essays of the Dublin Society*, octavo, London, 1740, page 203.

plant; and this is accomplished by a solution of the mucilaginous substance which occasions them to cohere. Putrefaction being the means employed to attain that end, hard water must be improper for steeping, because all such waters have the property of resisting the putrefactive process. Dr. Home, who made many experiments on this particular branch of our subject [49], assures us that flax may lie even four or five months in moss-water before it will be sufficiently steeped. Hence he recommends "that the steeping should be made a business distinct from the raising of flax," and says that in Holland it is managed by lint-dressers, who buy the flax standing on the ground, and carry it to their own premises to steep. He has also remarked that the flax, when properly watered, acquires a slippery oiliness on its skin, owing to a solution of the mucilage; but Pliny's rule is still the most certain, "*Maceratos indicio est membrana laxatior* [50]."

Should these cursory observations be the means of exciting a wish in any of our agriculturists to pursue the investigation of this subject, I would recommend to their perusal a series of letters on the management of flax, published in the Essays of the Dublin Society, already quoted; and as this book is not commonly to be met with, I shall transcribe a passage or two in confirmation of the foregoing assertions.

"Two parts in three of those who deal in flax,"

[49] See his *Treatise on Bleaching*, page 318.
[50] Plinii *Hist. Nat.* lib. xix.

says the writer of these letters, "seem to think that "every kind of water is equally good: but this is "certainly a considerable mistake, and has done "more injury to the linens of this kingdom than "our people are aware of. Notwithstanding the "best endeavours of our bleachers, our linens are "greatly inferior to those of the Dutch in colour, "and I know no more likely cause for it than the "impurity of the water employed. The clearest, "stillest, *softest* water is the best[11]."

"Hence the necessity of having settled flax-"dressers resident in convenient habitations, and "disposed in various places about the country. Our "itinerant undertakers take the water as they find "it, good or bad, as the place where they are em-"ployed affords it: therefore, let their skill be "otherwise what it will, this single circumstance "must defeat their best endeavours."

"The most eligible situation for the flax-dresser "is in the neighbourhood of a large lough, or a "still river, where there is a convenient spot for "laying out his ponds and reservoirs. The dresser "who would perfectly succeed must have ponds of "different kinds, for a small pond is less liable to "disturbance from winds than a large lake. 'Tis "probable, our people may object to the cost; but "I beg leave to refer them to the Dutch, who find "by experience that the best conveniencies are al-"ways the cheapest."

[11] Letter by R. M. No. 31, dated Nov. 8th 1737, in the *Dublin Essays*, page 131.

"As a situation favourable in every circumstance "cannot always be obtained, the flax-dresser may "sit down with safety in any place where there is "abundance of water, and room for reservoirs, "though the water should not prove of the best "and softest kind, spring waters excepted, which "obstinately retain their harshness. Any *stream* "sufficient to supply him, may with proper care be "made serviceable to his purpose. Admitting it "into his ponds betimes, and allowing it a longer "season to deposit, and receive the influence of the "sun and air, will make indifferent water equal to "the best. Where he has capacious ponds, 'tis the "dresser's fault if he has not good water. Who-"ever has such ponds may always procure good wa-"ter, and without them nothing but a scarce and "lucky situation can afford success [52]."

From the experiments which I have myself made in DYEING, I am convinced there are few of the dye-woods or other vegetable substances that are employed in that art, which will yield their colours freely to any but *pure* water. Dr. Bancroft discovered that if logwood be boiled in distilled water, it will give a *yellow* decoction [53], whereas we all know that a decoction of this wood when made with common spring water is of a full *red*, or a dark blood-colour.

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[52] See *Essays of the Dublin Society*, Letter 32d, page 135.
[53] Bancroft's *Philosophy of permanent Colours*, vol. ii. p. 341.

By the experiments of Dr. Percival it has been ascertained, that soft water acts more powerfully as a menstruum on vegetable bitters and astringents than hard pump water, and that it dissolves some resinous bodies without any medium, or at least with a much smaller proportion of mucilage than is commonly employed [34].

The baneful effects of impure water on the human constitution have been already noticed in a former part of this Essay [35]; and I am now desirous of impressing upon my readers the importance of their examining the nature of the water they drink, and of advising them, should it be impure, to adopt some of the means already recommended for obtaining it in a state of greater perfection. Herodotus relates, that in Ethiopia the inhabitants live to be an hundred and twenty years old; that they eat animal food and drink the water of their own country, which is so light that wood will not swim upon it, and that it is the use of this water that prolongs their lives [36]. Dr. Percival says that the Spaniards are entirely exempt from many of our cutaneous diseases; and the reason he assigns for this remarkable fact is, that the air of Spain is clear and

[34] *Experiments and Observations on the Pump Water of Manchester*, by Dr. Percival, octavo, London 1769.

[35] See page 388.

[36] Herodotus, lib. iii. cap. 125.

serene, and the water they drink pure and wholesome [87].

In the water of the Pei-ho river in China, the mud is suspended in such large quantities as to render it scarcely potable. This water is, however, quickly refined for use by the following simple process. A small lump of alum is put into the hollow joint of a bamboo, which is perforated with several holes. The water taken from the river is stirred about with this bamboo for three or four minutes, during which the earthy particles uniting with the alum are precipitated to the bottom, leaving the water above them pure and clear. Persons of rank in China are so careful about the quality of the water intended for their own consumption, that they seldom drink any but what has been distilled [88].

Not only the Chinese are careful about the quality of the water they drink, but from the most authentic information it appears, that the inhabitants of some parts of the East Indies have always been aware of the importance of drinking the very purest water. Mr. Harmer relates, that the Hindoos go sometimes to great distances to fetch water, and then they boil it that it may not be hurtful to travellers: after this, they stand from morning until night in some great road where there is neither pit nor rivulet, and offer it, *in honour of their gods*, to

[87] Percival's *Observations on the Waters of Manchester.*

[88] *Macartney's Embassy to China*, by Sir George Staunton, Bart. 2 vols. quarto, London, 1797, vol. ii. page 68.

be drunk by the passengers [89]. It was to this humane custom that an eminent teacher probably referred, when he told his adherents that if they gave a cup of cold water *in his name*, they should not lose their reward.

A short time ago a very neat and convenient apparatus in glass, for filtrating small quantities of water or other fluids, was contrived by Mr. William Haseldine Pepys, and has been sold in considerable numbers by Messrs. Knights, in Foster Lane, Cheapside. This instrument, I conceive, must be useful for many purposes besides that of purifying water, and therefore I have obtained leave to make a drawing of it to accompany this Essay [90].

The method of purifying water recommended by Professor Parrot of Paris, and which consists in passing it through sand or charcoal placed within a large inverted syphon, appears to promise a successful result. It will be found under the article "Filtration" in Dr. Willich's *Domestic Encyclopedia*, vol. ii. page 276. Several excellent modes of raising water are also well described in the same work, under the article "Water," in vol. iv. page 292.

It was formerly a general complaint that the health of maritime people was much injured by the internal use of water which had become in some degree putrid by age, or in other words by being

[89] See the *Asiatic Miscellany*, Calcutta edit. 1786, vol. ii. p. 142.

[90] See the Plate prefixed to this Essay, fig. i. ii. and iii.

kept stagnant for so long a period as is sometimes necessary on long voyages. In modern times, however, various expedients have been contrived to obviate this great inconvenience. Dr. Stephen Hales discovered that good wholesome water may be procured on a voyage by the distillation of sea water, if ¼lb. of chalk be previously mixed with every gallon of water put into the still. A remarkable circumstance respecting the obtaining of fresh water at sea by those who may be so unfortunate as to have their ship frozen up in the ice all winter, is related by Mr. Boyle. "An old sea captain," he says, "assured him, that when his ship was immured with ice in the frigid zone, so that they could not in a long time get so much as a barrel of salt water, he made wells of the thick pieces of ice, to receive the liquor of the thawed ice, and found this water (though on the main sea) to be good fresh water fit for drinking, for dressing their meat, and other uses, and that he never feared the want of fresh water in those seas [61]."

I am happy to embrace this opportunity of suggesting to those who may have to supply large vessels with stores, that it is always advisable to make choice of *hard* water for the use of the ship's crew, as this resists putrefaction, and consequently will keep good much longer than *soft* water. The inconvenience of having none but hard water to use

[61] Boyle's *Observations on Cold*, London 1683, Appendix, p. 15.

for the different culinary and domestic purposes, and the danger resulting from the continued drinking of such water, can be easily obviated by the use of an alkali, which might be employed occasionally to precipitate the impurities, and on such quantities only as would be required for the wants of those on board, as before directed at page 390.

Such ships as are fitted out from the port of London usually take in their supply of water from the Thames, as this water is said to possess properties which render it peculiarly fit for sustaining a long sea-voyage. At first, after being kept for some time, it turns in some degree putrid and offensive, probably from some kind of fermentation; after which it again becomes pure and palatable, so as to serve better than all others for sea-stock. Although the question is of great consequence, I have never yet heard any rational explanation of this phenomenon. "Water taken from the New River in London, says a writer in the Philosophical Transactions, stank very much after being kept stagnant for eight days, but when it arrived at Virginia it again became sweet[90]." The water of the Rhone, if it be suffered to stand for the impurities to subside, and then be put into *earthen* vessels, will not putrefy by heat, though it will soon become fetid if put into *wooden* ones [91].

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[90] *Philos. Trans.* No. 127, page 652.
[91] Act. Lips. 1683.

Dr. Priestley, in his Observations on Air, relates, on the testimony of Mr. Garrick, that the reservoirs for water in the town of Harwich are generally very foul on their sides and at the bottom; and that provided these are not cleansed of what adheres to them, they always preserve the water sweet, otherwise it will become fetid and unfit for use, and the vessel will not recover its sweetness till the sides and bottom grow very foul again. Dr. Priestley supposes, that what they call impurities is merely vegetating matter that adheres to the sides of the vessel, and imbibes every thing tending to putrefaction [64]. May not the change which is effected in the Thames water be attributed to a similar cause?

A curious fact has indeed been recorded by Dr. Boerhaave respecting the preservation of water in a wholesome state under the equator and between the tropics, where stagnant waters always breed an innumerable quantity of insects, and soon become extremely putrid. Water, he says, which has thus spontaneously grown offensive, may be easily rendered wholesome again, and this merely by occasioning it to boil for a moment; for this operation will destroy the animalcula, which, with the rest of the impurities, will subside, and then the addition of a very small quantity of any strong acid, particularly the sulphuric, will render it fit for use. Or if a small portion of sulphuric acid be put to the wa-

[64] *Observations on Air*, vol. ii. page 185.

ter at the first, this will preserve it from animalcula or from putrefying [a].

I must not however suffer this part of the subject to pass over without inserting a caution respecting the use of *leaden* reservoirs and pumps of lead, for the preservation and conveyance of water designed for drinking, because I have reason to believe that this practice has been attended with many very fatal consequences.

The poisonous nature of lead when taken into the stomach in a state of solution is now pretty generally known; but as lead when immersed in water is not soluble in that fluid, persons are apt to imagine that no noxious effects can arise from the use of leaden pipes and cisterns. But, though pure water of itself will neither dissolve, nor oxidize this metal, yet the oxygen of the atmosphere combined with the action of the water will convert it to an oxide, when it absorbs carbonic acid gas with avidity from the air, and this renders it capable of solution. The oxides of lead are insoluble in water, but a small portion of any acid, even one of the weakest kind (carbonic acid), will render them soluble. So small a portion as 16 parts of carbonic acid is sufficient to acidify 83 parts of oxide of lead, the whole of which then becomes soluble in water, impregnated with carbonic acid.

The white line which may be seen at the surface of the water in leaden cisterns, is occasioned by the

[a] Dallowe's *Translation of Boerhaave*, vol. i. page 348.

oxidizement of the metal; and as this oxide absorbs the carbonic acid of the atmosphere, the oxide of lead becomes converted to carbonate of lead, and is taken into the stomach of those who drink the water which has been standing in such receptacles. Dr. Percival, Dr. Johnstone, Sir G. Baker, Dr. Lambe, and other physicians, have related many deplorable instances of individuals and even whole families being taken off by this insidious poison. I have myself reason to believe that some years ago I lost an amiable and highly valued relative in this way, and therefore am desirous of inserting an account of these facts, in the hope of recalling the attention of the public to the state of their reservoirs for water, and thus being the humble means of prolonging, if not of saving, the lives of many individuals.

It is necessary, however, to offer a few remarks on some of the properties peculiar to water, and on the various applications of this important fluid. The more obvious properties of water have been mentioned in the early part of this paper, but there are several others to which it is also necessary to advert.

The different appearances and forms which water is capable of assuming have already been slightly noticed. Some further particulars however, deserve our attention.—In the state of elastic vapour it is perfectly transparent, or invisible to the eye. In this condition it is completely soluble in atmo-

spheric air; and though it may by increase of temperature be attenuated in so remarkable a degree, yet caloric, or the matter of heat necessary to convert it into vapour, is incapable of occasioning any permanent change or alteration in the chemical nature of this fluid.

Atmospheric air and water act reciprocally on each other. The former dissolves aqueous vapour, and water dissolves or absorbs atmospheric air. In its natural state, water is generally esteemed to be 850 times heavier than atmospheric air; but waters differ a little in their specific gravity. I found that a bottle which would hold only 4258 grains of distilled water at the temperature of 60° would contain 4260 grains of New River water, or 4262 grains of pump water such as rises in Goswell Street, London.

Christopher Clavius, the eminent German mathematician, poured some water into a bolt-head, and then sealed the mouth of its neck hermetically, and marked with a diamond the place to which the water rose at that time: he then hung it up, and eighty years afterwards it was found in Kircher's study, just as full as it was at first [66].

The great fluidity of water is one of its most remarkable properties [67]. It is this which renders it so useful in many of the mechanical arts, some

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[66] Dallowe's Edition of *Boerhaave*, vol. i. page 326.

[67] This property hath furnished Shakespeare with one of his beautiful similes:

"Men's evil manners live in brass, their virtues
We write in water."

of which I shall particularize hereafter; and it is owing to this that it has always a tendency to find its own level. Hence it has for many ages been employed to determine the plane of the horizon, and for other philosophical purposes. The solvent power of water is increased by removing the atmospheric pressure from its surface.

The experiment with the solution of sulphate of soda, related at page 363 of this Essay, though introduced for another purpose, is sufficient to prove this fact also; for the water holds all the salt in solution, no longer than the bottle is closely corked; and as soon as the action of the atmosphere is restored, part of the salt precipitates in a crystalline form. Hence, I conceive it to be extremely desirable to try whether some important effects in the art of dyeing, or rather in the processes of extracting the colouring matter of vegetable substances, by means of water, might not be produced by conducting those operations in a partial vacuum.

Another circumstance respecting water is, that its specific gravity is lessened, except in particular cases, by increase of temperature. This fluid might consequently be expected to increase in its specific gravity in exact ratio with its reduction of temperature; and this is found by experiment to be actually the case, till it be reduced to 42° of Fahrenheit; but after that it becomes specifically lighter by every further abstraction of caloric, and furnishes a memorable instance of one of those deviations from the usual course of nature which its omni-

scient and beneficent Author has appointed for the preservation of the world, and the welfare and felicity of its inhabitants. I need not, however, particularize, because the fact has already been sufficiently explained in the first volume of these Essays[68].

In a variety of chemical operations it is important to know the specific gravity of the water employed. A Table of its specific gravity from 30° to 80° Fahrenheit will be found in the 84th vol. of the Philosophical Transactions, and also in the 1st vol. of Mr. Brande's Manual, where it is accompanied by an example of its use in reducing the weight or bulk of water employed in any case, to that which it would have at any other common temperature. The solvent power of water is generally influenced by its specific gravity.

Having, in the foregoing paragraph, adverted to the solvent power of water, that circumstance has reminded me of a table of the solution of salts which I constructed some time ago for my own use. This table has been extremely serviceable in my own laboratory: I shall therefore insert it, in the hope that it may be of some use to many of those persons who may take the trouble of perusing these volumes. I cannot vouch for its perfect accuracy in every instance, as some of the experiments are difficult to accomplish; but I believe it will be found to be sufficiently correct for every purpose of real business.

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[68] See Essay II. vol. i. pages 58—62.

A New Table of the Quantity of Water required to dissolve 100 Pounds of each of the following Salts.

Salts.	At 60°.	Boiling.
Sulphate of Magnesia, 100 lbs. .	100	75
——— Ammonia	200	190
——— Potash	1670	500
——— ——— super . . .	200	100
——— Soda	500	224
——— Alumina and Potash .	2000	133
Nitrate of Lime	25	20
——— Magnesia	100	
——— Ammonia	200	50
——— Soda	300	100
——— Potash	720	50
——— Strontites	500	
——— Barytes	1120	335
Muriate of Lime	50	
——— Strontites	84	
——— Magnesia	100	
——— Soda	286	280
——— Potash	300	
——— Ammonia	340	100
——— Barytes	560	
Phosphate of Ammonia . . .	400	180
——— ——— Soda	400	200
Oxy-muriate or Chlorate of Potash	2000	304
Borax	1180	590
Carbonate (sub) Ammon. . .	200	100
——— super, ditto . . .		
——— sub, Soda	200	100
——— super, ditto . . .		
——— sub, Potash . . .		
——— super, ditto . . .	400	125

The ancients seem to have had very confused notions of the changes which are produced in the specific gravity of water by variation of temperature. All the information that Pliny gives on the subject

is comprised in a single sentence, and even this is calculated to convey an erroneous idea. "All water," says he, "grows to be heavier, after that mid-winter is once passed[69]."

It appears, however, that the contraction and expansion of water by change of temperature were well known to the early chemists. Bacon and Boyle[70] have both written expressly on the subject; but I know of no author (except Sir Charles Blagden and Mr. John Dalton) who has made any direct experiments to determine what kind of ratio is observed by this fluid, in its variation of bulk by the addition or abstraction of caloric. A Table compiled by the former of these philosophers will be found at the latter end of Chapter 3. of The Chemical Catechism, 10th edition, page 76, and that by Mr. Dalton I now copy from his own work[71].

A Table of the force of the vapour from water, in every temperature from that of the congelation of mercury, or 40° below zero of Fahrenheit, to 325° of that thermometer, is given in Rees's Cyclopedia[72]. Some important observations on the use of steam in the processes of decoction, solution, distillation, &c., will be found in the Appendix in an Additional Note to the Essay on Water.

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[69] Holland's *Pliny*, book xxxi. chap. 5.

[70] *Experimental History of Cold*, by the Honourable Robert Boyle; quarto, London 1683, pages 92 and 113.

[71] See Dalton's *New System of Chemical Philosophy*, Part I. page 29.

[72] See *Cyclopedia*, vol. xxxiv. signature D, page 6.

Mr. Dalton's Table of the Expansion of Water by Change of Temperature.

Temperature accor. to Fahrenheit.	Expansion.	Temperature accor. to Fahrenheit.	Expansion.
12°	100236	122°	101116
22	100090	132	101867
32	100022	142	101638
42	100000	152	101934
52	100021	162	102245
62	100083	172	102575
72	100180	182	102916
82	100312	192	103265
92	100477	202	103634
102	100672	212	104012
112	100880		

I have no doubt that the foregoing Table very accurately shows the variations of bulk in a determinate quantity of water; but it having occurred to me that one formed in a different manner might possibly be more useful to our manufacturers and other practical men, I undertook, some time ago, a series of experiments for that purpose, and the following Table was the result. The specific gravity-bottle and scales which were chosen on this occasion, are described in Vol. I. page 501, and are the same as were employed in making the Sulphuric Acid Tables which are printed in the 7th Essay.

A New Table of the Expansion and Contraction of Water by Change of Temperature. The Barometer at 29½ Inches.

Temp. ac. to Fahrenheit.	Contents in grains of a bottle holding 4265 grains of pure water at 42°.	Temp. ac. to Fahrenheit.	Contents in grains of a bottle holding 4265 grains of pure water at 42°.
32°	4260	92°	4240
34	4261	96	4237
36	4262	100	4234
38	4263	102	4232
40	4264	108	4228
42	4265	112	4226
44	4264	120	4220
46	4263	126	4214
48	4262	134	4208
50	4261	140	4199
52	4260	146	4191
56	4259	150	4185
60	4258	154	4180
64	4257	162	4172
68	4256	170	4160
70	4255	178	4150
74	4254	184	4142
80	4252	192	4130
84	4249	200	4116
88	4245		

Flattering myself that this table may be of very essential use in many cases of real business, I am desirous of giving an example of its application before I pass on to any other branch of the subject. Suppose a boiler, or other vessel of capacity, to hold 4260 pints, or 532½ gallons of water at any temperature on the range of Fahrenheit's scale between 32 and 52 degrees, by looking at the figures opposite to 150 in the second column of temperature, it will be seen that such boiler would con-

tain only 4185 pints, or little more than 523 gallons, if heated to that degree; and on looking at the last line, it will appear that such vessel would hold only 4116 pints, or 514½ gallons, at 200°: therefore, should a boiler be completely filled by 532½ gallons of water of the temperature of 52°, no less than 18 gallons of it would flow over the sides of the vessel before the remainder could be heated to 200°. The maximum of the density of water is at about 42°: this fluid therefore becomes of less specific gravity, whether it be heated above or cooled below that point. This accounts for the seeming anomaly in the table, by which it appears that water occupies the same room at 32° as it does at 52°.[72]

There are some phenomena of water which seem inexplicable, though the authorities I have for them cannot be disputed.

If water be thrown into a crucible of melted glass in a high state of incandescence in a glass-house furnace, the globules of water will dance upon the surface of the melted glass for a considerable time, like so many globules of mercury upon a drum-head; but if a small quantity, or even a pint, of water were to be thrown into such a crucible before the glass is completely fused and while the sandiver is upon its surface, the water would be rarefied into

[72] See this more fully explained in the *Manchester Memoirs*, vol. v. page 374, or in the Notes to the 3d chapter of *The Chemical Catechism*.

steam in an instant, an explosion would be the consequence, and the furnace would probably be blown into pieces.

In like manner does water sooner evaporate from a plate of iron that is heated to a red-heat only, than from one that has been brought to a welding heat, or nearly to the point of fusion.

Again, in the manufacture of black bottles it frequently happens, while the workmen are engaged in moulding and blowing the bottles, that the metal becomes more cooled than they could desire, so that they find it necessary to give directions to their attendants to throw in more coal and increase the fire. This, however carefully it may be done, will sometimes produce so much dust that the surface of the glass becomes covered with carbonaceous matter. Whenever this occurs, it occasions such a motion within the crucible, that the metal appears as though it were actually boiling; and if it were to be used in this state, every bottle would be speckled throughout and full of air bubbles. But as it would be very inconvenient to wait for the whole of this carbonaceous matter to be consumed by combustion, and as, by being partly mixed with the glass itself, it might occasion it to boil over the sides of the crucible, it was thought very desirable to discover an easy and *immediate* remedy for the accident, and this has been found in common water.

Whenever the accident occurs, the workman

throws a little water into each crucible; and this has the effect, not only of stilling the mass immediately, but it renders the metal as smooth and pure as before. This curious and almost instantaneous effect is probably owing to the water becoming decomposed, and affording its oxygen to the coal-dust, and converting it to carbonic acid gas, which immediately escapes and is dissipated in the atmosphere.

Nothing now remains but to describe some of the various USES to which water has been applied in different parts of the world, a knowledge of which I conceive may be turned to advantage by some classes of readers.

In enumerating the several purposes to which water has been applied in all ages and countries, I shall slightly pass over the account of the musical instruments of antiquity which were made to play various tunes by means of the pressure of water; and shall also decline any lengthened detail of the methods which were formerly adopted by superstition for the trial of supposed delinquents, by the immersion of the unhappy individuals in water, as these are matters more of curiosity than utility and improvement.

Andrew Brice, in describing one of the palaces of the Grand Duke of Florence, says, "The pilasters are adorned with an organ, which by means of water plays several tunes;" and in a note states,

that such hydraulic organs are to be seen in several grottos in Italy[73]. The invention, however, is not modern; for Cresibus of Alexandria, who lived in the reign of Ptolemy Euergetes, is said to have contrived them. Archimedes and Vitruvius have left descriptions of the instrument, and we find the figure of one on the reverse of a large medallion of Valentinian.

It was formerly a custom in several countries to weigh those that were suspected of magic, it being generally imagined that sorcerers were specifically lighter than other men. This was the origin of the practice of throwing the accused person into water; when, if his body floated upon the surface, he was convicted of witchcraft and burnt, but if it sunk to the bottom he was acquitted. M. Ameilhon has published a curious paper in the 37th vol. of the Memoirs of the Royal Academy, on this particular subject, in which he endeavours to show the probability that some of these miserable persons did actually float on the water. He states that among the multitude of persons subject to hysteria and other similar complaints there are several who *cannot* sink in the water; and hence he concludes that the pretended magicians and sorcerers who floated when tried by the *water-ordeal*, were persons deeply affected with nervous disorders. Pomme, the celebrated French physician, in his *Traité des Affections Vapoureuses*, supports the same opinion.

[73] Brice's *Geographical Dictionary*, folio, London 1759, vol. i. page 574.

Water may be employed as a mechanical power in some of our large manufacturing concerns with great advantage. In the 448th Number of the Philosophical Transactions, page 231, there is a description of a very ingenious water-bellows, invented by Mr. Triewald, for the use of iron forges and other furnaces, where a great heat is to be produced by forcing a large quantity of atmospheric air into the fire-place. Since the publication of that account, water-bellows upon different constructions have been employed in various parts of this kingdom, for the business already mentioned, and also by those makers of utensils in iron called iron-founders; but the power which may be thus given by water is so great, and the principle is in itself so simple, that I cannot help wishing it were more universally known; for I am confident that it might be brought into greater practice, and extended to a multiplicity of arts and manufactures to which it has not yet been applied. It is not possible, however, to give the reader an accurate idea of this curious mechanical contrivance without a drawing; I must therefore refer him to the copper-plate engraving which accompanies the account of it in the number of the Philosophical Transactions above mentioned[74].

Bellows moved by water have been long in use at the iron forges in Sweden; and water-bellows on a

[74] A plate of this machine, accompanied by a description of its several parts, may also be seen in the 10th volume of Baddam's *Memoirs of the Royal Society*, octavo, London 1741, page 396.

different construction, and which are employed at Tivoli in Italy, are described in one of the early volumes of the Philosophical Transactions; but those by Mr. Triewald are more simple and on a better principle.

In some particular situations, water is very profitably employed in drawing coals and other minerals from the bowels of the earth. Thirty years ago I recollect having been much gratified in viewing an apparatus of this kind which was then at work in the coal district of Derbyshire, I think somewhere near Ilam; it may be thus described:

Two wooden vessels, or buckets hooped with iron, are fastened one at each end of a very thick hempen rope, and this rope is made to pass over a large wheel which is fixed exactly perpendicular to the mouth of the shaft of the mine. In the commencement of the operation, one of these empty buckets is first lowered to the bottom of the pit, and when it is filled with coals, a boy who is stationed above, and close to the mouth of the pit, lowers the end of a leathern pipe which he holds in his hand, and this immediately fills the upper bucket with water. This being now heavier than the loaded bucket below, it begins to descend with considerable velocity into the mine, while the other ascends with equal speed and soon arrives at the surface, charged with the coal or other mineral designed to be raised. When the bucket of water reaches the bottom of the pit, it is interrupted by a strong iron pin placed vertically in the ground, exactly in the centre of the spot where the bucket must

rest; and this pin forces up a large valve in the bottom of that receptacle, allowing the whole mass of water to escape in an instant. The vessel which has arrived at the top of the pit being emptied, this is now, in its turn, filled with water, while the men below are loading the other with the mineral, which is then to be raised by the power of the descending water, as before; the buckets continuing to ascend and descend in rotation and without interruption. The specific gravity of water being only a trifle greater than that of a mass of loose coal, this circumstance renders water peculiarly fit for the use of a colliery in the manner above described.

It is obvious however that this contrivance cannot be adopted every where; but I am persuaded there are many places in this kingdom where minerals are raised at a very great expense, though their situations are in every respect favourable for the employment of this machine; and it is this consideration which made me desirous of explaining the scheme in this Essay.

Mines are, moreover, frequently opened on the side of a hill or mountain; and as springs of water are generally to be found in those situations, this method might be employed in all such places, provided there be either a rivulet at the bottom of the mine, or that a fissure in the rock can be found, to carry off the descending water.

I had forgotten to remark, that in providing a stream for setting this apparatus in motion, all that is needful is, to fix a wooden spout into the side of

a pool or other contiguous reservoir of water, exactly even with the surface of the water, and then to adapt a flexible tube of leather or other suitable material to that end of the trough which comes to the mouth of the mine. In considering this arrangement, it will be seen that the mere elevation of the leathern end of the pipe a few inches only, will entirely prevent the running of the water; the machine therefore may be kept in motion at any time by a child; and when it is not at work, all that is required is to hang the end of the pipe upon a hook fixed in a post at the side of the pit, when the current will instantly cease.

I might here attempt to describe the various methods of raising water from great depths; but as this would lengthen the Essay more than would be desirable, I must refer the inquiring reader to Nicholson's quarto Journal of Natural Philosophy, where he will find several elaborate memoirs on that subject, accompanied with plans and engravings [75].

A gentleman in the neighbourhood of London, who is desirous of having a reservoir of water at the top of his house, has it in contemplation to supply it by means of a common smoke jack: this machine, which will be in constant action, is to work an endless chain, to which a great number of small cups, capable of holding one or two ounces of water each, are to be attached, and these by the usual contrivance will empty themselves into the cistern in succession as they ascend.

[75] See Nicholson's *Journal*, quarto, vol. iv. p. 165—466.

The fertility of Egypt in consequence of the annual inundation of the Nile, is a matter of general notoriety; and many of the well informed agriculturists of these kingdoms, availing themselves of the knowledge of this fact, do periodically supply their estates with artificial currents of water, and derive great benefit from the practice.

The Chinese have long known how to value the practice of watering land artificially. "I observed," says Van Braam, "several mills which raise the water of the river above the banks, whence it runs into reservoirs, to be afterwards diffused, by means of canals and aqueducts, over the fields that require irrigation. These mills are of simple construction, and entirely composed of an assemblage of thin bamboos, except the axle-tree of the wheel, which is of timber. In no part is the smallest piece of iron or any other metal employed. The whole machine, as well as I was able to judge, is from 18 to 28 feet in diameter [76]." Being myself one of those who have never entertained a fear of the state being injured by the land becoming too productive, and recollecting that it was said of old, that he deserved well of his country who could make two blades of grass to grow where only one grew before, it is incumbent on me to recommend, in the most forcible terms, the practice of irrigation, and to urge its general adoption. M. Desmarets has given a me-

[76] Van Braam's *Embassy to the Court of the Emperor of China*, London 1798, vol. i. page 72.

moir on the best method of watering meadows, in the 3d volume of Memoirs of Agriculture, published by the Royal Society of Agriculture at Paris. A very satisfactory account of the way in which water acts on the different organs of plants, and assists vegetation, may be read in Fourcroy's System of Chemistry[77]. Several memoirs containing ample instructions for the general management of the business of irrigation may be seen in the Bath Agricultural Papers, in the Transactions of the Society of Arts, and in other similar publications. But I shall not have mis-spent my time, if, by making an extract or two from the works of some of the best writers on the subject, I should be the means of exciting the attention of any of our practical farmers, so as to induce them to adopt this very important and advantageous mode of culture.

The Reverend Mr. Wright says "that land by regular methods of watering, whatever be its kind and quality, is increased to double or treble its former value; that land under this management does not require dung, but is itself a constant source of manure to other fields; and that it raises grass in the spring a month sooner than the same fields could otherwise be made to yield it[78].

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[77] Fourcroy, vol. viii. page 359—366.

[78] See "*An Account of the Advantages and Methods of Watering Meadows by Art, as practised in the County of Gloucester.*" By the Rev. T. Wright. Small 8vo, London 1789. More information may still be obtained from a Letter which this Gentleman wrote to the Editors of the *Monthly Review*, and which is printed in the 78th volume of that work, at page 671.

Mr. Boswell, who has written a more elaborate treatise on this subject, says, "It is inconceivable what twenty-four hours water properly conveyed over the land will do in a dry season; a beautiful verdure will arise in a few days, where a parched, rusty soil could only be seen; and one acre will then be found to maintain more stock than ten acres without such management. Moreover, almost the whole of the expense in this mode of cultivation, is the actual manual labour of a class of people who can be employed in no other way for the support of their families; consequently the expenses can be comparatively but small, though the improvement must be great and durable[79]."

"Flooding," says another writer on this subject, "is truly the best of all improvements where it can be effected, and there ought not to be a single acre of land neglected which is capable of this practice[80]."

It is related of Mons. Pestre, a skilful physician and an enlightened cultivator of land among the Cevennes mountains, that at the first threatenings of a storm he used to clothe himself in a long garment of oil cloth, with an enormous hat of tinned iron firmly fixed by means of straps. Thus defended, he hastened into the midst of his possessions, where alone, with a mattock in his hand, he directed the water to the feet of his trees, and col-

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[79] Boswell's *Treatise on Watering Meadows*, illustrated with five copper-plates. Third edition, octavo, London, 1792, page 12.

[80] Kent's *Hints to the Landed Interest*, London, Oct. 1775.

lected the surplus in cavities which he had formed in the rock itself. By these exertions he constantly prevented injurious inundations on his estate, and procured water for his ground at such times when the burning heats rendered it necessary. His neighbours, who, as usual in such cases, at first derided him, were constrained to admire his industry and envy his gains; for, in consequence of this labour, he quadrupled the usual product of his grounds.

There is a most interesting and highly entertaining memoir on the means of improving mountainous districts, and from which I extracted this account, in the 3d volume of Nicholson's quarto Journal of Natural Philosophy, &c. page 295. "Much has been already done," said the late amiable Dr. Percival at the conclusion of his Essay on the *Orchis Root*, "for the advancement of agriculture, but the earth still teems with treasures which remain to be explored. The bounties of nature are inexhaustible, and will for ever employ the art and reward the industry of man."

Another equally striking proof of the influence of water on vegetation may be found in the very remarkable industry of the gardeners who cultivate the marshes near Paris. From these marshes, situate all around that great city, they derive large profits; they cover the ground with abundant and uninterrupted crops, and they are indebted for this almost astonishing series of vegetable production to the enormous quantity of water, which they are in-

ceaseantly conveying into their grounds[81], and to the continual waterings with which they fertilize them[82].

We read of a very extraordinary stream of water that supplies the public baths of St. Philip, in Tuscany, which carries a peculiar kind of earth, or earthy salt, in its current. This earth, when it is collected and condensed in the cavities of any body that is employed to oppose its course, acquires the nature, hardness, and colour of alabaster, and assumes the forms of the cavities in which it is thus collected. The ingenious Mr. Latapie, convinced by repeated experiments of this singular property of the water of these baths, had moulds made of several single figures, and even groups; and, by placing them in a certain manner against the current of this stream, he collected in their cavities the earth in question, and thus formed *basso relievos* of beautiful alabaster. This success enabled him at length to establish a manufacture, which has rendered the finest productions of sculpture more easily attainable in that part of the country than they had hitherto been, and much more precious by the accuracy of the copy[83].

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[81] One might imagine that Moses was acquainted with the advantage of irrigation to agriculture and gardening. "A river," says he, "went out of Eden to water the garden." Genesis, chap. ii. ver. 10.

[82] Fourcroy's *System of Chemistry*, vol. viii. page 359.

[83] For an account of this singular manufactory see *Rozier's Journal* for June 1776; or the *Monthly Review* for November 1776, page 391.

But it would be an endless attempt to endeavour to enumerate all the various kinds of water which have been noticed by the respective writers who have given us accounts of their travels into different parts of the world. I therefore conclude with the more pleasing task of inviting the contemplative reader to devote a moment or two to the recollection of a few of the more obvious advantages which we derive in every quarter of the globe from the possession of water.

Water is indispensable as the beverage of man and other animals; as the medium for conveying nourishment to vegetables; and for rendering effective those important senses of sight, taste, and smell. It has been well remarked, that that most wonderful machine the *eye* can only represent objects to our senses by the means of humours composed chiefly of water; and that the glassy coats of this important organ must lose their transparency, were they not constantly moistened with water.

I am supported in this assertion by the testimony of an anatomist of great credit and respectability. "Because," says he, "the outermost coat of the eye might be pricked, and this humour let out, therefore nature hath made provision to repair it by the help of certain *water*-pipes, or lymphæducts, inserted into the bulb of the eye, proceeding from glandules that separate this water from the blood [84]."

[84] Ray's *Physico-Theological Discourses.*

In like manner with regard to *smell*, the respective odours of bodies are collected, blended, perfected, and preserved, by means of water; nor could they be conveyed to the proper nerves had not nature supplied these parts with humidity, at once to lubricate the vessels, and to collect the odoriferous exhalation. "The use of this *pituïta*," says Mr. Cooper, "is to keep the membrane soft. By this means the olfactory nerves expanded on this membrane, are rendered capable of the perception of odoriferous effluvia, which otherwise the *dryness* of the part would destroy[85]." Neither is any body sapid, unless it either contain water or be dissolvable therein; for it is well known that those substances which are most soluble in water, soonest imprint the sense of taste upon the organs which are destined to receive that impression: a dry tongue can no more taste than dry nostrils smell, or a dry eye distinctly see[86].

The most beautiful tints of flowers[87] would also be unable to please us if they were divested of water; nor would any of the products of the vegetable kingdom be capable of fermentation, were it not for the intervention of this important fluid. Clay would be mere useless dust without water, and incapable of being modelled into any of the beautiful forms

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[85] Mr. William Cooper's *Dissertation on the Smell*, published in Drake's *Anatomy*, vol. ii. London, Third Edition, page 313.

[86] See Dr. C. Lucas *on Water*, 8vo, London 1756, page 79.

[87] Even the lustre of the diamond is often compared to water:

> ——— "'Tis a good form,
> And rich: here is a *water*, look ye."
>
> SHAKESPEARE.

in which we now see it, or applied to any of its present important uses. Lime and sand might be mixed and blended for ever without their forming a compact mass; but by the addition of water they acquire the property of hardening, and of forming for us excellent cements and durable habitations[88].

Almost all chemical operations require the presence of water, and many others cannot be conducted to any advantage without its assistance. The most powerful and heterogeneous salts, if perfectly dry, may be mixed without any seeming effect; and few if any decompositions could be produced without the agency of this all-pervading and important fluid. The processes of decoction, solution, distillation, precipitation, and crystallization, are all dependent upon water for their success. Starch, glue, and every other kind of mucilage, owe their tenacity to water; and it is probable that most of the substances on the face of the earth would fall into shapeless or pulverulent masses, useless and inert, were it not for the binding effects of this most accommodating and wonderful fluid[89].

There are also various reasons for believing that the salubrity of the atmosphere is preserved by means of water; and we are surely not a little in-

[88] I conceive that these assertions have already been abundantly proved by different illustrations in the former part of this Essay. See pages 363—366.

[89] Persons desirous of investigating this curious subject may read the first volume of Boerhaave's *Elements of Chemistry* with great advantage; also Campbell's *Political Survey of Great Britain*, quarto, vol. i. chap. v. pages 67—133.

debted to the Great original Contriver of all things for that immense accumulation of this fluid which is collected in the ocean, by means of which we are enabled, without labour or fatigue, to visit every clime on the surface of our globe; to barter the valuable products of each with one another; and to interchange all the important blessings of religion, literature, science, civilization, and the arts.

facture of sal-ammoniac[1]. In consequence of this, the traffic in muriate of ammonia became very considerable, and the ancient Greeks and Romans, who employed this singular salt for many purposes, procured their supply from that quarter. In process of time, the native Egyptians also learnt how to make sal-ammoniac, and for many ages the whole of Europe had no means of obtaining this salt, except by importing it from that country.

According to Pococke and Niebuhr, manufactories in later times were erected for the express purpose of making this saline compound, at Dsjise, at Geeza, and at Rosetta a sea-port on the coast of Alexandria, as it was found impossible for the whole of Europe to be supplied from the original manufactory.

In the year 1716 Geoffroy, a celebrated chemist and physician of Paris, read to the Academy a memoir on the composition of muriate of ammonia, and gave it as his opinion that it came from Egypt and was the product of sublimation. In the year 1720 he published an account of a series of experiments, to prove that sal-ammoniac might be made profitably in Europe.

Little was known however of the methods by which this salt was procured in Egypt, until the year 1719, when Lemere, the French Consul at Grand Cairo, sent an account of its manufacture to the Academy of Sciences at Paris, who published it in one of the volumes of their Transactions. I suspect this French Consul to have been a different

[1] Pliny, lib. xxxi. cap. 7.

person from Nicholas Lemery, the celebrated chemist of Rouen, who I believe died early in the eighteenth century. He might perhaps have been a son of the aforementioned Nicholas, for he was also an eminent chemist and likewise physician to the French king. The following is however an abridged detail of the process, as given by Lemere.

The natives of Egypt (says he) collect for this purpose the excrements of camels, oxen, and other animals which feed on saline plants. These excrements are dried by applying them to the surface of walls; and when they are sufficiently dry, they are burned as fuel in their common household fires. It is from the soot afforded by these burning substances that the muriate of ammonia is extracted. For this purpose the soot is put into large glass bottles 18 or 19 inches in diameter, terminating in a neck several inches high. These glasses are filled to within four fingers breadth of the neck, and gradually heated for 72 hours. Towards the second day the muriate of ammonia sublimes, and adheres to the upper part of the bottles. When the process is finished and the whole apparatus has been well cooled, the vessels are broken, and the lumps of ammoniacal salt are taken out for sale[1]. Five pounds of the soot procured from the burning of this excrementitious matter are expected to produce one pound of muriate of ammonia.

Here it may be worth observing that the soot of Newcastle coals will produce an abundance of sal-

[1] Fourcroy's *System of Chemistry*, vol. iii. page 275.

ammoniac. Some few years ago there was a considerable manufactory of this salt in the neighbourhood of London, which was supplied entirely by the common soot collected from the chimneys in the metropolis.

Respecting the African sal-ammoniac, other writers relate, that as sea salt is always given copiously to the camels, during their journeys in the caravans over the Desert to Alexandria, their urine and dung consequently become very replete with the salt. The dung of these animals being burnt in the public ovens for hatching chickens for the caravans, and also in their common fires for culinary purposes, the volatile salt is produced in the soot, and this requires only to be purified by sublimation, in order to form the cakes of muriate of ammonia which are exported to Europe.

Chaptal relates, that he obtained sal-ammoniac from the *soot* of cow-dung and that of horses, which run wild in the immense plains of Camargue and Crau, and upon the borders in the numerous marshes in the vicinity of the Mediterranean, but that he soon found he could only procure it from the dung of these animals while they continued to live on *marine* plants.

Another account of the Egyptian manufacture may be seen in Hasselquist's Travels in the Levant. It differs in some respects from the foregoing, but it is extremely interesting. He relates that the poor inhabitants of Egypt are occupied for several months of the year in collecting the excrementitious products already spoken of; that they mix these with cut

straw to assist its drying; that when dried they use it as fuel, having in reality no other kind; and that they make a business of collecting the soot from all parts of the country to sell to the sal-ammoniac makers at Grand Cairo.

When the origin of this volatile salt had thus been made known, it was soon discovered that it was a compound body; that it existed ready formed in some parts of the earth; and that it consisted of a peculiar alkaline substance, in close union with muriatic acid.

The acid which was found to be one of its component parts had been known for a century before, and employed for a variety of purposes; but this was not the case with its base, the ammonia, or volatile alkali, which engaged the attention of chemists for many years afterwards, and long before its nature and properties were at all understood, or that it had been even suspected to be any thing more than a simple undecomposable body.

Tournefort was the first chemist who asserted that sal-ammoniac is composed of muriatic acid and ammonia: he made this known in the year 1700. Muriate of ammonia is sometimes found in the environs of volcanoes, and in a state of solution in some lakes in Italy and Tuscany[3]. It exists also in the mountains of Tartary, in Thibet, and in the grottos in the vicinity of Pouzzola[4]. This salt is likewise found in the country of the Kalmucks, and

[3] Rozier's *Journal*, xvi. page 362.
[4] Fourcroy's *System of Chemical Knowledge*, vol. iii. p. 274.

sent from thence into various parts of Russia for sale. The specific gravity of muriate of ammonia is 1.420[5]; it is soluble in rather more than three times its own weight of water in the temperature of 60°, and in an equal weight of water when at 212°. Its solution produces cold.

According to the Baron Riedesel, muriate of ammonia is found plentifully in the neighbourhood of Mount Etna. He remarks that "the lava is not various and beautiful like that of Vesuvius, of which above forty kinds have been collected, for that the lava of this mountain contains chiefly iron and *sal-ammoniac*[6]. Wiegleb states, that sal-ammoniac is met with at the apertures and fissures of the internal crater of Mount Vesuvius, but that the sublimation is never observed till two months after the eruption[7].

Basil Valentine, who wrote in the 15th century, speaks of sal-ammoniac; and Geber, who lived 600 years earlier, classes it among volatile bodies, and gives directions about subliming it[8].

In the year 1773, Dr. Priestley separated the ammonia from sal-ammoniac by means of quick lime, and exhibited this alkali for the first time in the state of gas. He may therefore be said to have been the real discoverer of ammoniacal gas[9]. This

[5] Bp. Watson states it to be 1.450. See *Chemical Essays*, v. 67.
[6] Riedesel's *Travels through Sicily*, &c. translated by Foster, 8vo, London 1779.
[7] Hopson's *Translation of Wiegleb*, p. 226.
[8] See Russel's *Translation of Geber's Works*, London 1678, p. 7.
[9] See Priestley's *Experiments on Air*, octavo, London 1781, vol. i. page 166.

gaseous substance was afterwards examined by him in various ways, and he even succeeded in decomposing it by means of electricity; but it does not appear that he had conceived any idea of the nature of its composition, though he seems to have been well acquainted with the compound nature of the salt from which he extracted the alkaline gas. The honour of this latter discovery was reserved for Scheele and Bergman; and about the year 1785 Berthollet published a memoir which confirmed the account previously given by the foregoing chemists, that ammonia is a compound of nitrogen and hydrogen. Berthollet pronounced ammonia to be a compound of 121 parts by weight of nitrogen, with 29 of hydrogen, proportions which have since been almost exactly confirmed by other chemists [10]. It is probable, however, that the real composition of ammonia is 13 nitrogen, and 3 hydrogen, which will make its equivalent number 16. Muriate of ammonia, or sal-ammoniac, is composed of one proportional of ammonia 16 combined with one proportional of muriatic acid 34.5, and its equivalent number is 50.5.

Pure ammonia is known only in the state of gas. This gas has a very pungent and acrid smell, but when plentifully diluted with atmospheric air its odour is rather pleasant and refreshing; it is a colourless gas, and being much lighter than atmosperic air, it is of course volatile.

Ammonia is also caustic and corrosive, and will

[10] *Mémoires de l'Académie des Sciences*, 1785, page 316.

unite with oil into a saponaceous compound; but it has not the power of acting violently on animal substances like the fixed alkalies, potash, and soda.

Ammonia is capable of uniting with most of the acids, and forming with them neutral salts. Thus we have carbonate of ammonia, nitrate of ammonia, sulphate of ammonia, muriate of ammonia, and other salts, with this alkali for their base.

The sulphate and muriate of ammonia have been found native in the neighbourhood of volcanoes and in other parts of the globe: the triple salt called phosphate of soda and ammonia is found in human urine; and since the decomposition of sal-ammoniac has been understood, several other salts have been formed in the laboratory by its means for purposes of medicine and for various uses in the arts. Klaproth analysed a specimen of native sal-ammoniac from Mount Vesuvius, and found it to be an uncontaminated muriate of ammonia, free from sulphuric acid, though the salt must have been generated in an atmosphere impregnated with sulphureous exhalations. He considers this salt to be a product of the mountain; that its basis, the ammonia, is composed of the hydrogen and nitrogen from the water, and the atmospheric air, which during that great chemical operation of nature undergo decomposition; and that this ammoniacal gas, uniting with the acid gas from the decomposed muriate of soda of the sea water which finds its way into the volcano, forms the muriate of ammonia in question[11].

[11] Klaproth's *Analytical Essays*, vol. ii. page 68.

The Bokarian Tartary, a district of Usbeck Tartary, in Asia, also furnishes a native muriate of ammonia. Klaproth examined a specimen of this salt, and found it to consist of

Muriate of Ammonia	97.50
Sulphate of Ammonia	2.50
	100. [10]

We have also fluate of ammonia, the arseniate of ammonia, the acetate of ammonia, the oxalate of ammonia, and the phosphate of ammonia; the latter of these is much employed as a flux for the blow-pipe, and in making pastes to imitate precious stones.

None of the ammoniacal salts however are consumed or manufactured in such abundance as the muriate of ammonia, the immediate subject of this Essay; its uses and application are very general and too various to be enumerated, though the mention of a few of them will show the great importance of this saline compound.

It is employed by the dyer to moderate the action of nitric acid in the preparation of nitrate of tin, and also to modify the hue of some particular colours. The alkaline part of this salt is employed by dyers in connection with archil, an article which cannot be prepared without ammonia. It is likewise used by certain artists in the process of soldering; by the workers in copper and iron, to prevent the oxidizement of the metallic surfaces which they intend to cover with tin; in pharmacy, for the preparation of several important medicines; by the

[10] Klaproth's *Analytical Essays*, vol. ii. page 71.

makers of snuff, in order to render that article more stimulant and poignant; and by the manufacturing and philosophical chemist, for the production of artificial cold; for analysing certain metallic substances; for the extraction of pure liquid ammonia, and for the preparation of the ammoniacal salt with which smelling-bottles are filled, and which on account of its solid form is in a variety of ways convenient and useful. I have been informed by a chemist of Birmingham, that not less than 20 tons of sal-ammoniac are annually consumed in that town by the workers in metal only.

When chemists had discovered the methods of separating the volatile alkali from sal-ammoniac, and had become generally acquainted with the nature of this gas, attempts were soon made to discover other sources from whence it might be procured, besides that of muriate of ammonia. It had been perceived that it was frequently disengaged from animal and vegetable substances when in a state of putrefaction; it was therefore natural to examine a variety of these substances for its production, and it was soon found that fish, animal horns, bones, hoofs, &c. when submitted to dry distillation, would yield this curious and peculiar substance in abundance. It should be remembered that all the above animal substances yield ammonia exactly in proportion to the quantity of nitrogen contained in them. Dr. Austin asserts, that ammonia is always formed where iron rusts in water which has a constant communication with the atmosphere.

[13] See the *Phil. Trans.* vol. lxxviii. page 379.

A plentiful source of ammonia, accessible to the people of all countries, and at all seasons, having thus been discovered, it immediately became a desideratum how to combine it, at a cheap rate[14], with muriatic acid, so as to form muriate of ammonia, and preclude the necessity of sending in future to Egypt for a supply of this useful and important salt; and this gave rise to the several manufactories established in different parts of Europe for this purpose.

Wiegleb, the eminent German chemist, says that the first European sal-ammoniac manufactories were established in England and Scotland; that, soon after these, one was set up at Paris by Baumé, and then another at Brunswick in Germany, in the year 1759, by two brothers of the name of Gravenhorsts, which were followed by divers others. In the year 1756, a very considerable manufactory of this salt was established by Messrs. Dovin and Hutton at Edinburgh[15].

When the ammonia had been procured as above mentioned, the most obvious method of forming sal-ammoniac was that of a direct mixture of the acid with the alkali; but when the first cost of the two materials, the muriatic acid and the ammonia, was considered, together with the great loss of gas which is always sustained by the mixture of these two volatile substances, it was found that the pro-

[14] Various proposals to this end were printed in the first volume of Weber's *Physico-Chemical Magazine* for 1780.

[15] See Hugo Arnot's *History of Edinburgh*, 4to, page 601.

cess, thus conducted, could not be carried on to any advantage in this country.

At this period however the resources of chemists had become much augmented, and every eminent practitioner in Europe was beginning to avail himself of the method of forming new substances by means of *double elective attraction*, or an interchange of principles, arising from the mixture of different compounds, one of the most valuable branches of chemical science.

Here it may be remarked, that Stahl seems to have been the first person who propagated the idea, that a compound substance could not be decomposed without the intervention of some other substance which has a superior affinity for one of the component parts of the original compound. In the year 1718 Geoffroy published the first table of chemical affinity. This table was enlarged and improved by Gellert in the year 1750, and in the year 1775 Bergman gave to the world his inestimable treatise on elective attractions, which was published in English in the year 1785: and since then our knowledge of the subject has been much increased by Morveau, Kirwan, Wollaston, and other eminent labourers in this important department of science.

The knowledge of the property which several of the salts possess of mutually decomposing each other, naturally laid the foundation for the discovery of a more economical method of forming the muriate of ammonia, so as to avoid the great loss of gas which always happens on the direct mixture of liquid

ammonia with muriatic acid, of which there had hitherto been so much complaint.

This ingenious method consists in first saturating the alkali with sulphuric acid, which may be done with little or no loss of the ammoniacal gas, and then decomposing the sulphate of ammonia[16] which is thus formed, by the mixture of a determinate portion of muriate of soda. In this process it is observable that the sulphuric acid is not entirely lost, for it combines with the soda, and produces Glauber's salt.

The result of this mixture and of the reciprocal decomposition of the two salts just mentioned, being muriate of ammonia and sulphate of soda, it is customary to concentrate the saline mass by evaporation to that point at which, when the liquor becomes cold, the sulphate of soda will separate itself by priority of crystallization, and then to boil the remaining fluid to a dry salt, which, by an adequate degree of heat, is afterwards sublimed into solid cakes of sal-ammoniac, for sale.

By this process most of the sal-ammoniac made in this country has for many years past been prepared. But the price of the English salt has been so high, owing to the first cost of the materials and the expense of the process, that the foreign sal-ammoniac has been sold much cheaper; so that most of the consumers have given the preference to the

[16] Sulphate of ammonia consists of one proportional of ammonia 16 + sulphuric acid 37·5, which makes its equivalent number 53·5.

latter, and this has occasioned the consumption of the English to be limited and very inconsiderable. This state of things has however lately undergone a complete revolution; and from some circumstances to be adverted to hereafter, sal-ammoniac can now be prepared in England as cheaply as in any part of the world.

Sal-ammoniac does not acquire any new properties by the process of sublimation. In some works on the continent it is never sublimed, but merely inspissated by evaporation, and then moulded into the shape of a cone. In saying that the consumers preferred the *foreign* sal-ammoniac, I do not mean that this was on account of its quality, because it is undoubtedly more impure than that which is made at home; it was its price which gave it this preponderance.

A more economical process than the one already described, for making this very important salt, was devised some years ago. This consisted in decomposing the impure solution of carbonate of ammonia by means of gypsum, or sulphate of lime; and a Mr. Minish of Whitechapel obtained a patent for the discovery. Perfectly dry sulphate of lime consists of one proportional of lime, or oxide of calcium, 26·5+one proportional of sulphuric acid 37·5, and its equivalent number is 64.

In conducting the patent process, the rough spirit as it is called, or the aqueous product of the distillation of bones, is digested upon ground plaster of Paris; when, in consequence of a double de-

composition, carbonate of lime is formed, which precipitates, and sulphate of ammonia, which remains in the solution. The fluid containing the sulphate of ammonia is then poured from the precipitate upon a definite quantity of muriate of soda[17] (common salt), when another change takes place, which gives sulphate of soda and muriate of ammonia; and these are then treated and separated as the others, by sublimation.

This process was carried on for several years—till the term for which the patent was granted expired, when the proprietor relinquished the concern, and retired from business with an ample fortune, acquired by the manufacture of sal-ammoniac, merely in consequence of the great superiority of his process.

Another method of making sal-ammoniac was invented by Dr. Hector Campbell, which consisted in mixing the solutions of muriate of soda, sulphate of magnesia[18], and rough carbonate of ammonia technically called *bone spirit*. This process, in a theoretical view of it, appeared likely to be profitable, as it would give, if the decompositions were complete, three valuable products for sale, viz sal-ammoniac, carbonate of magnesia, and Glauber's

[17] Muriate of soda, in solution, consists of soda 29·5 + muriatic acid 34·5, which makes its equivalent number 64; but when desiccated it may be said to consist of 22 sodium + 33.5 of chlorine, which gives its equivalent number 55.5.

[18] Sulphate of magnesia, when perfectly dry, consists of 18.5 of magnesia + 37.5 of sulphuric acid, and its equivalent number is 56.

salt; but I have reason to think that it has proved otherwise, or the concern would not have been altogether relinquished. I have also some doubt as to the separation of the muriatic acid from the common salt by this mixture, because we know that muriate of soda and sulphate of magnesia are not incompatible salts, for they are constantly found together in considerable quantities in the waters of the ocean.

Much has been said at different times about the Liege process of making sal-ammoniac; which consists in mixing small sea coal, common salt, and the soot produced from pit coal, and then uniting these into a paste with tempered clay and water. The mass is afterwards formed into slabs in the form of flat tiles, and these are then placed in a furnace with bones, laid stratum super stratum, and the product of the combustion collected in appropriated chambers. When these furnaces are set to work, they are generally kept burning for five or six months.

This appears to me to be a better process than that of mixing the ammonia with *liquid* muriatic acid; but I am inclined to think it is too tedious an operation ever to become profitable in this country[19]. Weber states that the soot of the Dutch turf yields also a perfect sal-ammoniac by sublimation. The Earl of Dundonald advises to mix fresh

[19] An ample account of the Liege method will be found in Chaptal's *Chemistry applied to the Arts*, together with an account of the manner of conducting the sublimation. See vol. iv. page 178.

slacked lime with ground peat, and then to distill for ammonia.

In the year 1794, Lelievre, Pelletier, D'Arcet, and Giroud, eminent French chemists, were employed by the Committee of Public Safety in Paris, to make a Report on the divers means of extracting soda from sea salt with advantage; and they, in their account of that process, have given one which was at that time conducted by M. Leblanc, at St. Denis near Paris, for the manufacture of sal-ammoniac[20].

His method consists in decomposing muriate of soda by sulphuric acid in a kind of reverberatory furnace, the floor of which is covered with lead; and as the current of muriatic gas is determined into an adjoining leaden chamber, it is there, at the same instant, met by a current of volatile alkali, produced from a variety of animal matters, which they burn in three cylinders of iron, placed in a furnace, side by side of each other.

In this process, the vapours of the muriatic salt are condensed in the leaden chamber, not only by their combination with the ammonia[21], but also by means of an eolipile, which was heated by the same

[20] An extract from this Report was printed in the *Annales de Chimie*, tom. xix. page 58.

[21] If the stopper be taken out of a phial of muriatic acid, in the presence of some liquid ammonia, it will be seen, by the cloud of muriate of ammonia in vapour which will appear in the atmosphere, how eager these gases are to unite to form the new compound.

furnace in which the iron cylinders were fixed for the combustion of the animal substances.

The decomposition of the muriate of soda was not, however, entirely finished in this operation, because the sheet of lead which covered the floor of the reverberatory furnace could not, without melting, endure a degree of heat sufficiently strong to effect this purpose. The operator therefore moves the matter into a third reverberatory furnace paved with brick, where it receives a degree of heat sufficient to make it enter into fusion, and complete the decomposition. It was necessary for the proprietors of this establishment to complete the decomposition of the common salt, because the economy of their process consisted in the employment of the alkaline residuum for the production of crystallized soda.

This ingenious method of making sal-ammoniac is described likewise in the second volume of the Journal de Physique for the year 1794, p. 134, and it is there accompanied with a copper-plate engraving of the ground-plan of the furnaces and other apparatus employed in the process. This apparatus is so very different from any thing which I have seen in this country, and at the same time is so well contrived for the purpose, that I have thought it worth while to copy it and have it engraved, to accompany this Essay[92].

There is, however, a mode of making sal-ammo-

[92] See Plate 23 at page 437 of this volume.

niac, which I conceive would be more economical than any of those already mentioned. It consists in the employment of the bittern of the salt-works, or the mother-waters which remain after the extraction of common salt from sea water. This is not a mere theoretical notion, for the process has more than once been acted upon, and at this time large quantities of sal-ammoniac are actually made according to this principle in some parts of Scotland.

The desire of making this valuable and economical process for preparing muriate of ammonia from the bittern of the salt-pans more generally known, was the motive that induced me to render the manufacture of sal-ammoniac one of the subjects of these Essays.

. . .

The preparation of this important salt by means of bittern is not, as I have said, a new process, for I recollect reading an account of it many years ago in one of the volumes of the Annales de Chimie[23], and in other works; but knowing the Board of Excise in England would neither allow the use of bittern, nor even the burnt pickings of the salt-pans, free of excise duty, I imagined this to be one of those processes which are interdicted by the high price of the materials, till an accidental circumstance which occurred a few years ago recalled my attention to the subject in a very particular manner.

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[23] See *Annales de Chimie*, tom. xx. page 186.

Mr. Astley of the town of Borrowstoness near Leith, who had taken out a patent for the manufacture of sal-ammoniac by combustion, in which he proposed to burn bones, blood[94], and other animal matters, with the bittern, proceeded by due course of law against a gentleman of the same town for having infringed his patent, and the cause came to be tried before the Lords of Session in Scotland. The question, however, not having been determined by the Court, it was agreed between the parties to defer final judgement until the opinions of some practical chemists in London should be obtained on the subject; and it was during my examination before the Commissioner appointed by the Lords of Session to take our report, that I first obtained the information that the Board of Excise allows the inhabitants of *Scotland* the bittern of the salt-works free of duty.

On acquiring a knowledge of this fact, a question immediately occurred—If the inhabitants of one part of the empire are allowed an article which is capable of being used in our manufactories duty free, why should not the same indulgence be universal in England and Ireland, as well as in Scotland?

Reflecting still more and more on this subject, and knowing that the riches of a country depend in a great measure on its producing within itself

[94] Dr. Thomson says, that if the fibrous part of blood be left in water it soon putrifies, and then yields more ammonia than any other animal substance.

most of the articles required for its own consumption, I think it right to make this circumstance more generally known; in the hope that some competent person, possessing the advantages of capital and a favourable locality of situation, would petition the legislature for leave to commence such an undertaking, and thus relieve the country from the necessity of sending into another quarter of the globe for a supply of this valuable and necessary commodity.

If a company of persons accustomed to the manufacture of sal-ammoniac was established in the neighbourhood of any of the salt-works in Cheshire, or near the salt-pits of Droitwich in Worcestershire, and could obtain permission from Government to use the bittern which is produced at either of those establishments, and which at present is thrown away as a useless residuum, I am certain that such a company would be enabled to afford the article in question much cheaper than the English sal-ammoniac has been sold for many years past, and at a rate which would effectually prevent the importation of ammoniacal salt from any part of the East. There are considerable salt-works in the Isle of Wight, and on the opposite coast at Lymington in Hampshire; but at both these establishments the salt is procured by the evaporation of sea water.

About a century ago, a work of the kind which I have here recommended, was established by one Goodwin a chemist of London [25], in which he pro-

[25] *Institutes of Experimental Chemistry*, 2 volumes octavo, printed by Nourse, London 1759, vol. i. page 347.

duced sal-ammoniac by mixing the bittern of sea water with putrid urine; but where this manufactory was situated I have not been able to learn. Baumé formed a similar establishment in France, where he decomposed the muriate of magnesia contained in the bittern of sea water, by means of a rough ammoniacal liquor procured from the distillation of animal substances.

I find also, from the testimony of Mr. Dossie, that a like establishment was formed about the year 1740, under the sanction of a patent[26]; but he does not inform us either of the names of the party, or of the place where their operations were conducted; though it appears from the form of his narrative, that both these establishments were dissolved in consequence of their great distance from the salt-works whence the bittern was produced, and the inevitable expense of the remote conveyance of an article of so much bulk and little value. These obstacles would not however intervene, were a manufactory to be established, as I propose, in the immediate vicinity of a salt-work; because bones and other refuse animal matter can be obtained any where.

The chrysalides of silk-worms are very productive of carbonate of ammonia. Hence several districts in Italy, and other parts of the continent, might be found where a manufacture of this alkali could be established with advantage.

It still however appears to me, as I suggested

[26] *Institutes of Experimental Chemistry*, vol. i. page 348.

several years ago in another publication [97], that the best situation for a manufacture of ammonia is on the sea coast, where pilchards, herrings, or the dog-fish, arrive in such immense shoals as to be periodically employed in manure for land. The dog-fish (the *Squalus canicula* of Linnæus) is caught all along the coast of Scotland from Peterhead to Bamff. They generally follow the herrings, and might probably be caught wherever shoals of herrings are found. The value to the fishers is in the liver, of which they make oil: therefore, the carcase, after extracting the liver, is sold for manure. They are caught with hand lines, and sometimes in such quantities that the boats come in as deeply loaded as they can swim. The dog-fish is usually from 30 inches to 36 inches in length, and they are sold, after the extraction of the liver, at 2*s*. 6*d*. per hundred, consisting of 140 fish, and seven of these hundreds weigh about a ton. By proper management, the body of this fish would certainly prove a very profitable article for the production of ammonia.

At Bamberg, in the circle of Franconia, the Germans have long been accustomed to boil the sediment of the salt-pans with stale urine, and sell it cheap for making sal-ammoniac. A similar kind of salt is still prepared in the neighbourhood of Vienna. In several other parts of Germany, and particularly in the vicinity of Gottenburgh, ammonia is pre-

[97] See *Chemical Catechism*, chap. vi. p. 137.

pared from the dregs which remain after the expression of train oil. Why might not the whale blubber be employed for the distillation of ammonia? Means might be devised for correcting its offensive smell, and rendering it very productive of volatile alkali.

The ingenious Mr. Dossie, already mentioned, who was a manufacturing chemist of the last century, and who had the honour of being one of the first English writers who undertook, with a noble superiority to all considerations of private advantage, to describe and elucidate many of the most important chemical processes without reserve, has, however, fallen into a considerable error respecting the use of bittern; an error which has probably misled many, and may have been the occasion of deterring some individuals from establishing the identical mode of making sal-ammoniac which I am now so anxious to explain and recommend. In order to correct this mistake, I shall copy what this respectable writer has advanced upon the subject [28], and shall then endeavour to explain how this misconception has arisen.

He says, that "in the English manufactures of sal-
"ammoniac, the vitriolic ammoniacal salt, which
"greatly resembles the true sal-ammoniac, in its ap-
"pearances and qualities, has generally been pro-
"duced instead of the true, as the sal *catharticum*

[28] Mr. Dossie was author, not only of *The Chemical Institutes* already mentioned, but also of a very useful work entitled *The Elaboratory laid open*, &c. octavo, London 1758.

" *amarum*, a *vitriolico-terrene* neutral salt, con-
" tained in the bittern or mothers, left after the ex-
" traction of the salt from sea-water, was employed
" for furnishing the acid."

" The reason of this substitution of the vitriolic
" acid for the other, was owing to this circumstance,
" that the spirit of salt is not found naturally in any
" other state than combined with the natron in the
" form of sea salt; which natron attracting the acid
" with a power superior to that of the volatile al-
" kaline salt, such acid could not be brought to
" combine with the volatile salt, without some pre-
" vious analysis or separation were made of it from
" that stronger alkali. This is indeed practicable,
" by means of distillation with oil of vitriol; or by
" burning the animal substances, designed to pro-
" duce the volatile salt, *together with the sea salt*;
" in which case the spirit being separated, com-
" bines with the volatile alkali *as it is formed* in the
" burning matter, and the combined elements sub-
" lime in the form of the true sal-ammoniac.

" But such a previous distillation of the spirit is
" laborious and expensive; and the burning the ma-
" terials and salts together, as this is only to be
" done with an *open* fire, and not in a close vessel,
" (the separation of the spirit not being to be ef-
" fected but on the principle of combustion,) oc-
" casions the dissipation of a great part of the salt
" produced. Also, the principle of combustion re-
" quiring *solid* materials to be employed to afford
" the volatile salt, this excludes the use of urine."

The conclusion which Mr. Dossie draws from what he has said, viz. that *pure* sal-ammoniac cannot be made by the admixture of carbonate of ammonia with bittern, appears to have been occasioned by his supposing that sea-water consists only of muriate of soda and *sulphate* of magnesia; whereas, a large portion of magnesian *muriate* is also contained in it. This becomes decomposed as soon as it is added to the ammoniacal liquor, and the result, as far as the muriate of magnesia is concerned, is the formation of a true sal-ammoniac.

Before I proceed, it may be observed that a considerable degree of practical experience is necessary in order to enable a manufacturer to produce a neat article of sal-ammoniac by this process of sublimation. With a moderate heat it attaches itself to the surface of the vessel in a loose spongy state, and is then called *flowers* of sal-ammoniac; whereas, if this volatile salt be raised by a strong fire, a *solid* sublimate is obtained; but if the heat be too intense, part of the product is in danger of being dissipated and lost.

The extraction of the ammonia on the principle of combustion adverted to by Mr. Dossie, must doubtless arise from the necessity of a constant supply of fresh atmospheric air; for I recollect Dr. Woodhouse of Pennsylvania asserts, that if he luted his stills he could never obtain the proper quantity of ammonia; but when he operated without lute he procured five times as much of this alkali from any determinate quantity of bones as he otherwise could.

When urine is employed for the production of ammonia, it is necessary to keep it till it becomes putrid, this alkali being one of the products of putrefaction. In summer *one* week will generally suffice, but in cold weather it ought to be kept three weeks or a month.

It is not, however, very surprising that Mr. Dossie should have fallen into the error respecting the bittern just noticed; for even Fourcroy, who died but lately, overlooked the magnesian muriate, and describes the waters of the ocean as containing only "muriate of soda, sulphate of magnesia, sulphate of lime, and much extractive matter[29]."

On the contrary, Bergman's analysis of a sample of water taken up at the depth of sixty fathoms, shows no portion of magnesian *sulphate*. The analysis of sea-water by Lavoisier, which gives 1958 parts of solid matter of various kinds in 10,000 parts of sea water, is as under:

1375	muriate of soda,
256	muriate of lime and magnesia,
156	muriate of magnesia,
84	sulphate of magnesia and soda,
87	lime.
1958	

The latest analysis which can be depended upon, and perhaps the best, is that by the late

[29] Fourcroy's *System of Chemical Knowledge*, vol. iv. p. 409.

Dr. Murray[30], who obtained by the evaporation of a pint of sea water,

Common salt	180.5 grains
Muriate of magnesia	23.0
Sulphate of magnesia	15.5
Sulphate of lime	7.1
	226.1

By this estimate it appears that the proportion of muriate of lime, and muriate of magnesia, in sea-water is considerable; I am, therefore, fully justified in recommending the use of bittern for the preparation of the ammoniacal muriate, and the production of magnesia.

Another advantage will also result from the use of this refuse article, which is this, that the *sulphate* of magnesia may also be rendered efficient towards the production of sal-ammoniac; inasmuch as it will decompose the liquid carbonate of ammonia, and form ammoniacal sulphate, which, by the addition of common salt, may at any time be converted to the true ammoniacal salt of which we are now treating. If the process be thus improved and carried to its full extent, the products for sale will be sal-ammoniac, carbonate of magnesia, and Glauber's salt.

It is important to remark, that the mixture of a proportion of sulphate of ammonia with the true sal-

[30] *Transactions of the Royal Society of Edinburgh*, vol. viii. p. 205.

ammoniac will, for many purposes, be no injury: for instance, the ammoniacal sulphate is well adapted to the soldering of metals, and equally applicable with the muriate of that alkali for the preparation of liquid ammonia, although it is not quite so productive of alkali.

Some further information on the affinities of ammonia and on several of its compounds, may be obtained from Lewis's edition of Neumann's Chemistry, vol. i. pages 336—353; Fourcroy's System of Chemical Knowledge, vol. ii. pages 323—354, and vol. iii. pages 272—284; in several of the volumes of the Annales de Chimie; and in the Quarterly Journal of Science, vol. iv. page 268, vol. v. pages 74 and 368, vol. ix. page 405, vol. xiii. page 226, and vol. xiv. page 203.

On the nature and properties, and on the formation and decomposition of muriate of ammonia, or sal-ammoniac, the Annales de Chimie may be consulted, viz. Westrumb on its decomposition by magnesia and carbonate of magnesia, vol. ii. pages 118—136; Vogler on its effects with madder in dyeing linen and cotton, vol. iv. pages 115 and 144; Dr. Blagden on its use in freezing water, page 236; on its analysis, vol. xiv. page 210; Hassenfratz on its specific gravity, vol. xxviii. page 13; Fourcroy and Vauquelin on the change in the form of its crystal by its union with urea, vol. xxi. page 67, and vol. xxxii. page 130; on its extraction from urine, page 162; Mons. Virey on its formation in volcanoes, vol. xxxvi. page 290; Vauquelin on its

existence in tobacco, vol. lxxi. page 153; Berzelius on its composition, vol. lxxix. page 233, and vol. lxxxi. pages 5—13.

Although I have given so many processes for making muriate of ammonia, I must not omit to advert to another source from whence this salt has of late years been obtained. By the distillation of common pit-coal to procure carburetted hydrogen gas for the purposes of illumination, a considerable quantity of ammoniacal liquor is obtained in the condensing vessel. This liquor, which contains a portion of carbonate and sulphate of ammonia in solution, is sold to the makers of sal-ammoniac, who obtain the salt from it by the following process. It is first treated with sulphate of lime, and afterwards with sulphuric acid, which is added gradually until the whole of the carbonate of ammonia is decomposed, and a sulphate of ammonia formed. By subsequent evaporation of the superfluous liquor the sulphate of ammonia is obtained in crystals. At other times common salt is added to the solution of sulphate of ammonia; and this, by the play of chemical affinities, produces two new salts, viz. sulphate of soda, and muriate of ammonia. The liquor containing these two salts is then reduced in quantity, by evaporation, to that point at which it is known by experience that the sulphate of soda will separate itself on cooling. When this salt has been removed, the remaining liquor is then evaporated till the muriate of ammonia will crystallize, as has already been described

at page 449. After this the muriate of ammonia is dried carefully, and then by the usual process of sublimation, it is formed into cakes of the true sal-ammoniac. I refrain from stating the product of muriate of ammonia that may be obtained from any given quantity of the ammoniacal liquor, as there is perhaps no article of commerce that varies more in quality than this residual liquor. At the large gas works in Worship Street, London, where every thing is conducted with great judgement and ability, I have understood that care is taken to preserve all the ammoniacal liquor, and endeavours are made to sell it of one uniform quality.

Having thus entered rather fully into the merits of this subject, and having especially explained the process of making sal-ammoniac by means of bittern, I have now only to remark, that I have no doubt, when a proper application is made to the legislature to release the bittern of the salt-works from the cognisance of the excise when employed for the manufacture of sal-ammoniac, that the people of England will be put in as favourable a situation in this respect as those of Scotland; the first object of every British senator, next to that of preserving the tranquillity of the state, being to strengthen the resources and encourage the manufactures of the country.

Ormus, the celebrated depôt for the sale of the merchandize of the ancients, and the grand capital of an Arab monarch, is in itself the most parched and barren spot in the world, where the people re-

ceived even the water they drank from a neighbouring country: but it became rich by the cultivation of trade, and the commerce of this otherwise miserable island made it the envy of the surrounding nations [31].

Long has the island of Britain in like manner enjoyed the blessings and luxuries which arise from an extended trade; and though we are now in the possession of the greatest part of the traffic of the world, we must not expect to preserve this proud pre-eminence, unless the Government determine to pay the most sedulous attention to our most minute interests as a manufacturing and commercial people.

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[31] See Campbell's *Political Survey of Great Britain*, quarto, vol. i. page 36.

In these early times mention is also made of *shears*, and of the shearing of sheep [3]; and yet many of the ancient nations knew nothing of iron, but used stones, flints, the horns and bones of various animals, the bones and shells of fish, reeds, and thorns, for every purpose in which the moderns now use edge tools of iron and steel [4].

Cutting instruments of *stone* are frequently found in various parts of Asia and Europe, particularly in the tombs of the ancient inhabitants of Peru [5]; and in Carmania, a province of Persia, hammers frequently occur which are made entirely of stone. These are known by the name of *Ceraunia*, or thunder-stones, and are preserved in some cabinets. They are perforated for the reception of handles, in the place most proper for receiving them, so as to leave no doubt of their having been intended for hammers, and used in the same way as we employ such implements at the present day [6].

There is a very circumstantial account of the stone weapons of the ancients, accompanied with several copper-plate engravings, in Dr. Woodward's History of Fossils. The same writer informs us that Captain Dampier found such implements still in use at Guam, one of the Ladrone Islands, and also in Nova-Britannia, an island lying south of

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[3] *Genesis* xxxi. 19. also xxxviii. 12, 13.
[4] Goguet's *Origin of Laws*, &c. vol. i. page 140.
[5] *Ibid.* vol. i. page 156.
[6] Agricola *De Natura Fossilium*, lib. v. cap. 13. pag. 262

the equator and the furthest to the east of any then known [7].

Herodotus, in describing the ceremonies which the Arabians observe in making alliances, says, that "on these occasions some one who is connected with both parties stands betwixt them, and with a sharp *stone* opens a vein of the hand of those who are about to contract. He then takes a piece of the vest of each person and dips it in their blood [8]."

The ancient embalmers of Egypt were in the habit of using an Ethiopian stone for opening the dead bodies, in order to take out the bowels [9]; and it may be presumed, from its being the practice to circumcise with a sharp flint [10], that edge tools of iron, if they were known, were not very common among any of the primitive nations.

Hesiod, who lived probably a thousand years before the time of Christ, says plainly, that "the plough-share was made with a species of very hard oak [11]; and from his manner of describing the ploughs that were then employed, there is no reason to suppose that any iron was used in constructing them.

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[7] Woodward's *History of Fossils*, octavo, London 1728, page 40.

[8] Beloe's *Herodotus*, book iii. § 8.

[9] Herodotus, lib. ii. n. 86. Goguet's *Origin of Laws*, vol. i. page 198.

[10] "Then Zipporah took a sharp stone," &c. *Exodus* iv. 25.

[11] Hesiod. *Oper. et Dies*, ver. 436. Goguet's *Origin of Laws*, vol. ii. p. 185.

The following is a modern translation of the passage to which I allude:

"If hill or field supply an *ilex* bough,
Of bending figure like the downward plough,
Bear it away; this durable remains,
While thy strong steers in ridges cleave the plains;
If with firm nails thy artists join the whole,
Affix the share-beam, and adapt the pole [19]."

Dr. Kirwan, the late president of the Royal Irish Academy, who had travelled much on the continent of Europe, used to relate, when speaking of the difficulty of introducing improvements in the arts and manufactures, and of the prejudices entertained for old practices, that, in Normandy, the farmers had been so long accustomed to the use of ploughs whose shares were made entirely of *wood*, that they could not be prevailed on to make trial of those with *iron*,—that they considered them to be an idle and useless innovation on the long established practices of their ancestors; and that they carried these prejudices so far as to force the Government to issue an edict on the subject. And even to the last, they were so obstinate in their attachment to plough-shares of wood, that a tumultuous opposition was made to the enforcement of the edict, which for a short time threatened a rebellion in the province.

On the arrival of the Saxons in Great Britain, our ancestors were in as low a state of civilization.

[19] Elton's *Translation of Hesiod's Works and Days*, line 586—591.

One of their laws enacts, that no man should undertake to guide a plough who could not make one, and that the cords with which it is drawn should be formed of twisted willows [13].

We have no testimony that Moses made use of iron in any part of the tabernacle which was prepared in the wilderness; neither have we any evidence that Solomon employed that metal in the construction of the Temple at Jerusalem [14]; though, in times antecedent to these periods, they made iron axes for hewing wood [15], and tools of iron for cutting stones [16].

It was probably the difficulty which the Hebrews found in making iron, and the consequent scarcity of that metal, which occasioned its not being employed for purposes of building, and it was perhaps of too great value to be brought into common use in those remote times; a conjecture which seems to be warranted by the language of their great lawgiver himself, who tells the people in his description of Palestine, that it is "a land whose stones are *iron*, and out of whose hills they may dig *brass* [17]."

A few centuries after this period, Homer describes Achilles as offering a large quoit of iron for

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[13] *Leges Wallicæ*, page 283.

[14] See Goguet, vol. i. page 161.

[15] "When a man goeth into the wood with his neighbour, to hew wood, and the head slippeth from the helve," &c. *Deuteronomy* xix. 5. In the original Hebrew it is, "the *iron* slippeth from the *wood*," as may be seen in the margin.

[16] *Deuteronomy* xxvii. 5. [17] *Ibid.* viii. 9.

one of the prizes at the games instituted in honour of Patroclus; from whence it would appear that this metal was still an article of considerable value.

"Then hurl'd the hero, thundering on the ground
A mass of *iron*, (an enormous round,)
Whose weight and size the circling Greeks admire,
Rude from the furnace, and but shaped by fire.
Let him whose might can hurl this bowl, arise,
Who furthest hurls it, take it as his prize [18]."

Madame Dacier on this passage remarks, "It must be remembered, that in those times *iron* was very scarce; and a sure sign of this scarcity is, that their arms were usually of *brass*."

If any kind of edge tools of iron were in use at this period, their employment must have been confined to but few individuals; for several ancient authors assert that Dædalus, the Greek architect, who flourished in the age immediately succeeding that in which the temple was built, knew nothing of the saw. The invention of this instrument they ascribe to the nephew of Dædalus, who, as they say, having accidentally met with the jaw of a serpent which he used with success to divide a small piece of wood, thus acquired the first idea of the use of such an implement [19], and soon afterwards formed a metallic instrument in imitation of it [20].

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[18] Pope's *Homer's Iliad*, book xxiii. line 973.

[19] Diodorus Siculus, lib. iv. p. 219. Ovid. *Metam.* lib. viii. verse 241.

[20] The invention of the potter's wheel is also attributed to this young architect.

Of all the metals, there is none which is so universally distributed over the face of the earth as iron; but the heat which is necessary for the separation of it from the ore is so intense, that we cannot wonder at many nations remaining long entirely ignorant of its use, and even of its existence; or that, when the knowledge of making it was lost at the Flood, a long period should elapse before this curious art was entirely recovered.

Accordingly, we find that spears and other instruments for exterminating wild beasts, and even implements of agriculture [91], were formerly made with gold and silver; and in confirmation of this, Diodorus Siculus says that the Arabians, "because they have abundance of gold, and contrarily are in want of brass and iron, exchange the one for the other with merchants [92]." Jonston says, that "at the island of Zabur, fourteen pounds of iron were bartered for 250 pounds of gold [93]."

As the wants of mankind, however, increased, many of the purposes to which these precious metals were applied were accomplished by means of copper, this being a metal more easy to be procured than malleable iron. Thus we find that the domestic implements and most of the instruments of war of antiquity, which in our times are occasion-

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[91] Diodorus Siculus, lib. i. p. 19. Goguet's *Origin of Laws*, &c. vol. i. p. 153 &c.

[92] Cogan's *Translation*, folio, London, 1653, page 141.

[93] Jonston's *History of the Wonderful Things of Nature*, folio. London 1657, page 123.

ally found in every quarter of the globe, are all either of copper or brass. Until very lately, indeed, all the edge tools that were in use in the island of Japan were of copper, or made with some alloy of that metal [24].

It is related among some of the earliest historical facts now on record, that Simeon and Levi, two of the sons of Jacob, entered Sechem sword in hand, to slaughter the inhabitants of that city[25]; but it is very probable, as the President Goguet has shown, that these swords were not of steel but of copper: therefore, if the Hebrews had the means of hardening and tempering copper, as it has been asserted, very powerful weapons may have been made with it, especially if they alloyed it with some other metal or metals, as was the practice with the ancient inhabitants of Peru, when they employed it in the fabrication of edge tools [26].

The abundance of celts and other instruments of antiquity, found in every country of Europe, as well as in a variety of places in other quarters of the globe, shows that copper and brass were formerly in very general use. Macrobius, who wrote in the fourth century, tells us, that when the ancient Etruscans intended building a new city, they marked out its limits with a coulter of brass; and that the priests of the Sabines were in the habit of cut-

[24] See Goguet's *Origin of Laws*, vol. i. page 158.
[25] *Genesis* xxxiv. 25.
[26] Goguet, vol. i. page 159.

ting their hair with a knife of the same metal [67]. In the sacred books we read of fetters of brass. See Judges xvi. 21.

There is one circumstance, however, which shows that instruments of *steel* were known to the ancient Egyptians, and, after them, to the Greeks and Romans. What I refer to is the existence of obelisks, statues and urns of *porphyry*, which, though of undoubted antiquity, are curiously carved and engraved, in a way which could not have been effected with tools of a common temper. It has been generally understood that nothing but emery or diamond powder would touch porphyry, and I believe we have no tools at the present day that are capable of engraving it. The porphyry obelisks at Rome are however not only very curiously carved, but graven also with hieroglyphics; and though these are distinctly cut, the obelisks themselves have not suffered in the least by their exposure to the weather through so long a series of ages. This shows their extreme hardness, and how highly the tools must have been tempered by which they were sculptured and engraved. Among other notices in the 8th volume of the Philosophical Transactions, at page 6014, "to retrieve the art of hardening and tempering of steel for cutting of porphyry," is mentioned as an important desideratum. See more on this subject in the Appendix.

In the time of the Grecian historian Agathar-

[67] Macrobius, *Saturnalia*, lib. v. cap. 19. page 512.

cides, who lived nearly two hundred years before Christ, chisels and hammers of copper were very commonly found among the rubbish of old mines: and since that period hatchets of copper have been discovered in the tombs of the ancient Peruvians [28]. All these may probably have been very useful utensils, especially if the fabricators of them were acquainted with any method of giving hardness to that metal.

It may here be remarked, however, that because no iron instruments of considerable antiquity are now found, we are not to conclude that the ancients never employed iron for such purposes; for it is easy to imagine that tools of iron or steel may have existed, and been destroyed by the hand of time. Iron is so necessary for the support of animal and vegetable life, that nature has endowed it with an affinity for oxygen, carbon and sulphur, much greater than that of most other metals, in order that it might be universally distributed. It is therefore difficult to conceive how an implement of iron could lie in the ground for a thousand years without being destroyed.

But to return to our subject. The President Goguet, a writer of great credit, and whom I have often quoted in this Essay, has asserted that the Count de Caylus, who died nearly sixty years ago, had discovered the art of tempering copper, "so

[28] Many authorities for these facts may be seen in Goguet's *Origin of Laws*, vol. i. page 158.

as to bear the grindstone, and be possessed of all the properties of iron" for the purpose of manufacturing edge tools [29]. I am, however, constrained to say that I very much doubt the accuracy of this account, though, if it were so, it is much to be lamented that he did not impart the secret for the purpose of its being made public. Sage, however, has announced that by combining *phosphorus* with copper, he has made it resemble steel in colour, grain, and hardness, and absolutely fit for a variety of purposes to which steel has hitherto been applied [30].

If we inquire respecting the state of the metallic arts among the ancient Britons, it will appear, from the prodigious numbers of copper instruments of different sizes and kinds which have been found in this country, such as axes, swords, spear-heads, arrow-heads, &c., all of which are known among antiquaries by the general name of *celts*, that our ancestors were well acquainted with the art of forming metallic copper in any way which they thought proper [31].

So lately as the year 1735, more than one hundred of these copper celts were found on Easterly-moor, twelve miles from the city of York, together with several lumps of metal intermixed with a quantity of foundry cinders, so that there can be no

[29] Goguet, page 159.

[30] See Nicholson's *Journal*, octavo, vol. ix. page 268.

[31] See Leland's *Itinerary*, vol. i. page 117. Henry's *History of Great Britain*, vol. ii. page 138.

doubt of there having formerly been a forge at that place for making such articles [32].

The war-chariots of the ancient Britons afford abundant proof that they were expert in the working of metals as well as in the modelling of wood. "The *Covinus*," says Dr. Henry, "was a war-chariot, and a very terrible instrument of destruction, being armed with sharp scythes and hooks for cutting and tearing all who were so unhappy as to come within its reach. It held few men, but was designed to be driven with great force and rapidity, and to do execution chiefly with its hooks and scythes [33]."

Notwithstanding the abundance of iron ore which this country affords, it appears that the use of metallic iron is comparatively but of late introduction: for at the time of the first Roman invasion, this metal was so scarce and rare a commodity that the Britons fabricated their money with it, and even the trinkets for adorning their persons [34]. But when the Romans had made themselves masters of the country they established imperial foundries for making iron, and built forges for manufacturing spears, lances, battle-axes and implements of every kind, in different parts of the kingdom [35].

Accordingly we find that the offensive armour of

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[32] Borlase's *Antiquities of Cornwall*, page 283.

[33] Mela, lib. iii. cap. 6. Tacitus, *Vita Agricolæ*, cap. 36.

[34] Cæsar, *de Bello Gallico*, lib. v. cap. 12. Henry's *History of Great Britain*, vol. ii. page 139.

[35] Henry, page 140.

the cavalry in the time of William the Conqueror was a long spear or lance pointed with *steel*, very sharp and well tempered; the long and broad sword double-edged, and a short dirk or dagger[36].

The mention of these weapons affords me the opportunity of saying, that in the Annales de Chimie there is an account of a considerable treatise by Vandermonde on the manufacture of bayonets and the blades of sabres. This work, which was undertaken by order of the Committee of Public Safety, contains a very minute detail of the various manipulations in the manufactory at Klingental, in the department of the Lower Rhine, accompanied with nine copper-plate engravings; and the treatise is spoken of by the editors of the French Journal in terms of the highest approbation[37].

The art of working in iron and steel had arisen to such a state of improvement in the 10th century, that even the horses of some of the chief knights and barons were covered with steel and iron armour. Artificers who wrought in iron were so highly regarded in those warlike times, that every military officer had his smith, who constantly attended his person, to keep his arms and armour in order. The chief smith was an officer of considerable dignity in the courts of the Anglo-Saxons, and Welsh kings, where he enjoyed many privileges, and his weregeld was much higher than that of any

[36] Hoveden's *Annals*, page 350, col. 1.
[37] *Annales de Chimie*, tome xix. page 47.

other artificer. In the Welsh court the king's smith sat next to the domestic chaplain, and was entitled to a draught of every kind of liquor that was brought into the hall [38].

The skill which our ancestors acquired under the instruction of the Romans, seems never to have been lost; for at the battle of Hamildon in the year 1402, the repulse of the Scots appears to have been entirely owing to the goodness and excellent temper of the arrows which were employed by the English army. Even the armour of the Earl of Douglas, which had been three years in making, was perforated by them; for, as the account states, "they were so sharp and strong that no armour could repel them [39]."

Dr. Martin Lister was of opinion that the ancients made their instruments *hard*, and converted them into *steel*, by one and the same operation; that they first fashioned them out of good soft wrought-iron, and then boiled them, as he expresses it, in fluid cast-iron. I have no doubt but that good steel might be made by this process [40].

We read but little of *swords* in the beginning of the 15th century, though no doubt they were then in use, since there is the evidence of Geoffrey Chaucer, who died only two years before the memorable

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[38] Henry's *History of Great Britain*, octavo, vol. iv. p. 127.

[39] Walsingham's *Historia Brevis*, page 366. Henry, vol. x. page 193.

[40] See *Philosophical Transactions*, vol. xvii. page 865.

battle of Hamildon was fought, that Sheffield was, even then, famous for its cutlery:

> " A dagger hanging at his belt he had,
> Made of an ancient sword's well tempered blade;
> He wore a *Sheffield* whittle in his hose[41]."

Table-knives, which probably were not in use in the time of Chaucer, were first made in London in the year 1563, by one Thomas Matthews of Fleet-bridge[42]. I have not been able to ascertain the date of the introduction of other kinds of cutting instruments; but when the utility and convenience of these domestic implements were once experienced, there can be no doubt that the practice of using them quickly became very general, and that manufactories of knives and other edge tools were consequently soon established in various parts of the kingdom. But in whatsoever manner this may have been, what has been offered will suffice to give the reader some idea of the progress of the art of cutlery, and of its gradual introduction into this country.

It is time now, however, to say a word or two respecting the design of this Essay, which is principally intended to explain some of the most important of the modern processes in *tempering* edge tools, and to point out such improvements as have occurred to me while examining some of the ma-

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[41] Chaucer's *Canterbury Tales*.

[42] See *The present State of Great Britain*, London 1683, page 77.

nipulations of the various artists who are now employed in the different branches of cutlery, and in the manufacture of steel [43], both in its cementation and the operation called tilting.

Good edge tools cannot be made without steel, which, according to the analysis of Vauquelin, is generally nothing more than soft iron combined with a small portion of carbon, silica and phosphorus, and sometimes a minute quantity of manganese [44]. Steel acquires the magnetic property better than iron. Hence good mariners' compasses cannot be made without needles of steel. The different kinds of steel may in some measure be known by their specific gravities [45]. The smell of putrid garlic, which is emitted by steel when dissolving in diluted sulphuric acid, is probably owing to the small portion of phosphorus contained in this compound metal.

Our makers of steel always use Swedish iron for this purpose. That which comes from Roslagen, a district in the neighbourhood of Upsal, is the best. The steel which is produced from it is, in its first

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[43] For an account of the methods of making steel consult Cramer's *Elements of the Art of Assaying Metals*, octavo, London, 1741, page 344—350; the article STEEL in Macquer's *Chemical Dictionary*, vol. iii.; or Chaptal's *Chemistry applied to the Arts*, vol. ii. page 197.

[44] Vauquelin, from the *Journal des Mines*, in Nicholson's Quarto *Journal*, vol. i. page 210.

[45] See Dr. George Pearson's Memoir, in the *Philosophical Transactions* for 1795, page 324.

state, denominated *blistered* steel. A very particular account of the method of making steel at Dalecarlia in Sweden, will be found under the article *Steel* in Keir's Translation of Macquer's Chemical Dictionary. The various sorts of steel are made by very different managements, and are thus rendered suitable for as many different purposes.

It may, however, be noticed that the largest English steel-works are at Newcastle-upon-Tyne, at Masbro near Sheffield, at Stourbridge, at Birmingham, and at the Brades. At Newcastle between twenty-five and thirty thousand weight of steel is cemented at a single operation, in two cases contained in one furnace. The operation lasts five days and five nights.

There are five kinds of steel generally employed in this country; viz. *blistered*, *shear*, *spur*, *star*, and *cast steel*. The cheapest sort of edge tools, and all articles of minor importance, are usually made with the first-mentioned kind, united to a large proportion of bar-iron. Clothiers' shears, firmer chisels, plane-irons, coopers' adzes, scythes, reaping-hooks and large knives, are commonly made with what is called *shear* steel. The *spur* and the *star* steel are used only for particular purposes, and these according to the fancy of the master cutler [46]. Besides these, there is also a German steel which is made immediately from the iron ore, by simple

[46] *Memoire sur l'Acier*, &c. By J. J. Perry, Correspondent of the Royal Academy of Beziers, &c. 8vo. Paris, 1779.

fusion. Vandermonde and his associates have published an account of the mode of producing it [47]."

Shear steel is prepared by a peculiar process. Several bars of common steel are laid together and regularly heated in an appropriate furnace, until they acquire the welding temperature, when they are beaten together by a massy forge-hammer, and then drawn out again into bars for sale. By this second operation the blisters are removed, and the texture of the metal is much improved.

Mr. Joseph Collier to his observations on Iron and Steel in the Manchester Memoirs has annexed a drawing of a furnace for converting bar iron into steel, with a full description thereof, which is worth the attention of persons interested in this subject [48]. An abstract from this paper, together with the plate, may be seen in Nicholson's Journal [49].

The different kinds of iron and steel vary very much in price. The following were the prices of most of the sorts in the London market, when the first edition of this work went to press. If I can obtain an accurate account of the present prices, I will give it in the Appendix to this volume.

Common bar iron, 15*s*. and 16*s*. per cwt.

Best Swedish iron, 22*s*. and 24*s*. per cwt.

Common steel, usually called blistered steel, 60*s*. to 66*s*. per cwt.

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[47] See Nicholson's Quarto *Journal*, vol. ii. page 64.

[48] *Manchester Memoirs*, vol. v. page 109.

[49] Nicholson's Quarto *Journal*, vol. iii. page 88.

Shear steel,
Star steel,
Spur steel,
} 84*s*. to 100*s*. per cwt.

Cast steel rolled into sheets, 10*d*. to 12*d*. per lb.

Cast steel drawn into bars, 1*s*. to 14*d*. per lb.

The high price of Swedish iron is owing to the great superiority of its quality when compared with common English iron; and this is attributed to the circumstance of its being manufactured with *wood* charcoal, whereas most of the English iron is prepared by means of mineral coke. The Swedish iron, however, differs very much in its quality; even one part of the same bar will often be of much greater value than the other. Formerly the wire-workers in Yorkshire used to go to Sheffield to buy foreign iron, on account of the circumstance above mentioned: it was usual with them to cut the bars into two-feet lengths, and then to select only such pieces as were fit for their purpose, leaving the other to be converted into steel. It is no uncommon thing to find a bar of foreign iron tough on one side and quite hard and brittle on the other. If such iron be exposed to the weather, this would soon become apparent by one side rusting and the other remaining quite clean, owing probably to the unequal distribution of the carbon in its manufacture.

I have also been informed that we have no artist in England who can make iron-wire fit for musical instruments, and that all such wire is imported from Holland, and sold at very extravagant prices.

The larger kind, such as is used in a piano-forte, cannot be bought for less than 8*d.* or 10*d.* per ounce.

With regard to *cast* steel, the best penknives, scissars, and razors; fine saws, surgical instruments, and every edge tool which requires a fine polish, together with a great variety of implements employed in cutting iron, are now all made with cast steel.

There are several cogent reasons for the preference of cast steel, for its nature is totally different from that of every other species. The proportions of the substances which combine with iron to convert it into steel are comparatively very minute; it is therefore necessary that these should be intimately and uniformly blended with the whole mass, and this is better effected by fusion than in any other way. By the fusion which this particular steel undergoes, the grain becomes closer, and the metal consequently much harder. These causes are sufficient to account for cast steel bearing a higher polish than most other kinds.

Five-and-twenty years ago the French had no knowledge of the process by which we prepare cast steel. The Committee of Public Safety, however, were very desirous of having the French cutlers instructed in this art, and they commissioned Vandermonde, Monge, and Berthollet to investigate the mode of its preparation. Some time afterwards, these eminent chemists published a memoir on the subject; and, in the true spirit of republicanism, they recommended the dilapidation of the principal

buildings and establishments of the ancient monarchy; and, considering the changes which have since taken place in their government, it is amusing to observe their enthusiasm. "Fellow-citizens," say they, "let us convey to our forges those expensive balustrades and railings which have nothing to defend, and if we find them to possess the qualities of good iron, let us convert them into steel." But it is probable that these individuals were afterwards ashamed of such barbarous sentiments, for I observed, when the memoir was republished in the Annales de Chimie, the passage which I have just quoted was omitted [50].

The superior beauty of those instruments which are made with cast steel would have occasioned a very great consumption of this article, had it not been for the difficulty of welding or uniting it properly with iron, and which, at first, occasioned it to be employed only for those smaller instruments, such as lancets and penknives, which are generally made entirely of steel.

However, it is necessary to be a little more explicit on this part of our subject. Bar-iron cannot be welded to another piece of iron unless both be heated to nearly 60° of Wedgwood's pyrometer, which is equal to 8.877°of Fahrenheit's scale, and is called the *welding*-heat [51]; but if cast steel be heated

[50] *Annales de Chimie*, tome xix. page 42.

[51] For an account of some experiments by Sir James Hall on the temperatures of iron, see the sixth volume of the Edinburgh *Philosophical Transactions*, page 71.

to this point, it would be fused, and run from under the hammer; and hence it was for a long time deemed impossible to use it in conjunction with iron, in the same manner as the other kinds of steel are employed.

Some nicety is required even in the process of welding iron, that the outside of the metal does not oxidize too much and fly off in scales, before the inside is brought up to a welding-heat. When, therefore, a skilful workman is about to weld two pieces of iron, he carefully observes the progress of the heat; and if one becomes too hot, he rolls it in sand to preserve it from the action of the atmosphere; and when one piece acquires the necessary temperature before the other, he covers that with sand while he brings the corresponding piece up to a sufficient heat for it to unite properly with the former. Silica when mixed with the oxide of iron forms a very fusible compound, which covers the work under operation, and prevents a further oxidation of the metal.

I have said that it was formerly deemed impossible to unite cast steel to iron by welding; but about thirty years ago it was discovered by Sir Thomas Frankland, who made many experiments on this subject, that if the cast steel be made only of a *white*-heat, and the iron of a welding-heat, the steel will then be soft enough to unite with the iron, and yet the former will not become fluid by the operation. It will, however, be proper to give the

necessary temperatures to the two metals separately, and then to unite them at one single heat[18].

Since this important discovery, cast steel has been brought into more extensive use, and the instruments which are thus constructed are much better than those which are made entirely of cast steel. The circumstance of an instrument having its back made of iron, renders it not so apt to fly from the work to which the edge or steel part is applied, and eventually less liable to break.

Mr. Nicholson, in his annotations on a Memoir by Vandermonde and others, informs us, he is convinced from his own experience that *cast* steel is preferable not only for polished steel goods, but also for cold chisels and all hard gravers for turners in metal.

I have been the more desirous of mentioning these particulars, because, on a late journey into the country, I have conversed with several ingenious cutlers, who had no idea that it was possible to unite iron and cast steel by the operation of welding. Many artists, long after the invention of cast steel, used to unite it to the iron by means of rivets. Hoes are still made by riveting or screwing the back, together with the eye, upon a blade made with cast steel.

Besides the various sorts of steel already enumerated, there is a peculiar kind which is manufactured at Bombay, called *wootz*, which admits of a higher

[18] See the *Philosophical Transactions* for the year 1795, page 296.

temper than any other steel[53]. Mr. Stodart of the Strand forged a piece of wootz for a penknife, at the temperature of ignition in the dark. It then received the requisite temper at 450°, and the edge became as fine, and cut as well, as the best steel instrument. From this experiment, this ingenious artist gave it as his opinion that wootz is superior, for many purposes, to any steel used in this country. He thought it would carry a finer, a stronger, and a more durable edge and point, and that hence it might be particularly valuable for lancets and other fine chirurgical instruments[54].

I have thought it right to relate these particulars, because there is a probability that the French and the Americans will be competitors with us for the trade of the continent[55]; and I esteem it of great importance, that no opportunity should be neglected of directing the attention of our respective artists to every circumstance that can have a tendency to preserve the superiorty of our national manufactures.

Mr. Mushet of the Clyde Iron-works, a gentleman who has probably paid more attention than any other individual in Europe to the properties of iron and steel, has written an interesting paper on the properties of wootz, in which he gives an account of the

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[53] See an account of experiments on wootz, in the 85th volume of the *Philosophical Transactions* for the year 1795, page 322.

[54] *Philosophical Transactions*, vol. 85, page 326. Mr. Faraday on the Analysis of Wootz, in *The Quarterly Journal of Science*, vol. vii. page 288.

[55] The Americans have for several years past directed their

separate analysis of five cakes of this foreign production, which he undertook at the desire of Sir Joseph Banks and sent to the Royal Society. The memoir is printed in the Philosophical Transactions and in Nicholson's Journal. In concluding this important communication, he makes the following remarks on the East Indian ore from which wootz is made: "The possession," says he, "of this ore for the fabrication of steel and bar-iron, might to this country be an object of the highest importance. At present," he adds, "it is a subject of regret, that such a source of wealth cannot be annexed to its capital and talent[96]."

The methods which are employed in making edge tools, are almost as various as the articles themselves. It cannot, therefore, be expected that I should describe in detail, or even completely understand, the nature of every process, especially as I was never personally engaged in any branch of the manufacture. The enumerating of a few of the more important of the manipulations, on which the artists chiefly rely, will, I trust, be deemed sufficient.

The cooper's adze and the carpenter's axe are

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attention to the manufacture of iron and steel. A valuable memoir on this subject, by Mr. Daniel Little, will be found in the 1st volume of the Memoirs of the American Society of Arts, quarto, printed at Boston, 1785.

[96] *Philosophical Transactions*, vol. 95, for the year 1805, page 175. Nicholson's *Journal*, vol. xi. pages 221 and 284.

first formed by the white-smith in iron, together with the eye for the helve. This being finished, the instrument is again heated, and then the edge of the cutting part is slit down with a chisel, and this slit filled with a thin piece of steel, of a corresponding size and form. The iron which had been slit open is then folded down upon the steel, and the whole is again submitted to the action of the fire till the metal acquire a welding-heat, when the sledge-hammer quickly unites the iron and the steel into one compact mass. When the white-smith is desirous of finishing these implements in the best manner, he allows them to be beaten on the anvil more than is absolutely necessary for putting them into the proper form, because the more the metal is hammered the tougher it becomes. This is the chief reason why horse-nail *stubs* are chosen for making chains and other works in iron which require great tenacity.

Scythes and such other large instruments are forged at the mill, by means of a large hammer moved by water. The process is called *skelping*.

Augers, gouges, large chisels, table-knives[58], razors, and other instruments of a similar bulk, are forged upon a large anvil by the principal workman, aided by an assistant called the *striker*, who stands

[57] The method which is adopted of converting old nails into bar-iron is curious, and may be seen fully described in Aikin's *Chemical Dictionary*, vol. i. page 600.

[58] A very particular description of the mode of forging table-knives and forks will be found in vol. x. of Rees's *Cyclopædia*, Sig. 4 N, article "Cutlery."

on the side of the anvil opposite to that where the chief operator stands, and puts in a heavy blow with a sledge-hammer occasionally, while the former is fashioning the instrument with a small hand hammer, and turning it round on the anvil, that it may receive now and then a blow from the sledge-hammer on those places where he perceives that it is required. This is usually done with considerable adroitness, and by these means such instruments are fashioned in a quarter of the time that would be necessary for the purpose if they were forged by a single workman.

For making the articles which are enumerated in this list, shear-steel is generally employed, as it is necessary such instruments should be entirely free from flaws; and this would not be the case were the common steel to be used for them. A facility is given to the forging razors and some other instruments, by the steel being previously drawn out to a correspondent size at the tilting-forge.

Penknives, lancets, gravers, surgical instruments, and other small edge tools, are generally forged on a small anvil firmly fixed within a large one in order to give greater steadiness. These are usually fashioned out of steel only, and forged by one workman singly and alone. Scissars are also forged by a single hand: but the anvil on which they are fashioned is of a peculiar construction, having *bosses* or *dies*, and *beak* irons of various sizes occasionally adapted to it, so as to suit the different shapes and

dimensions of the separate parts of these particular instruments.

The beak-iron, or bickern as it is sometimes called, is a round taper instrument fixed upon an anvil in an horizontal direction, and designed for fashioning hollow work upon, which could not be beaten upon the straight face of the anvil. Some anvils have beak-irons adhering to them, and others have square holes at one end for a moveable beak-iron to drop into.

It should have been noticed, that many other tools besides the axe and the adze are originally forged out of a piece of iron, with a little steel welded to it for the cutting part of the instrument. I have also heard of one instance in which the steel is affixed to a tool of *cast* iron, and that an excellent instrument is produced by this method. This is in the manufacture of Bingley's patent plane-irons, which are constructed in the following manner.

It is well known that it is the circumstance of drawing down the *shear*-steel under the tilt hammer that gives it the superiority over common steel. Mr. Bingley therefore thought that, if he could roll out his steel much thinner than it had ever been done before, he should improve its quality; and accordingly a very thin piece of steel is let into the face of a plane-iron made of cast iron; and, as the steel for this particular purpose has to go through the rollers several times to make it sufficiently thin, it becomes of a peculiar texture, and the tool made

with it is found to suit the joiner much better than the plane-irons heretofore in use.

In the manufacture of edge tools, the process which immediately succeeds the forging is that of *hardening*. All these cutting instruments are therefore fashioned when the metal is in its originally soft state; and when they have attained the intended forms, they are heated afresh to a particular temperature suitable to the article. When they have acquired that degree of heat, they are instantly plunged into cold water, which gives them great hardness, and renders them capable of cutting soft iron or even steel.

The best cutlers have ascertained that it is always desirable not to give an instrument a greater degree of heat by this operation than is absolutely necessary; but this will be better understood as we proceed in describing that process[59].

Nothing augments the hardness of steel but increasing the *coldness* of the water; and hence some have had recourse to the solution of salts in the water to be employed in hardening. A stream of running water will make steel harder than *still* water, as fresh portions of the same fluid are incessantly presented to the heated metal. Some cutlers have assured me that they can make the best instruments when they employ urine in the process of hardening. May not this be attributable to the

[59] See Nicholson's Quarto *Journal*, vol. iv. page 128.

phosphoric salts contained therein, as it has been demonstrated that phosphorus is one of the component parts of steel?

It is now generally understood that hardening by means of the strong mineral acids has no peculiar advantage; but I find that Reaumur, from his own experience, recommends the use of diluted nitric acid[60]. For the discoveries which this eminent man made respecting the conversion of iron into steel, the Duke of Orleans settled a pension upon him of 12,000 livres a year; and, at his request, this was settled upon the Academy, to be applied after his death for defraying the expenses of future attempts to improve the arts[61].

Experience has proved that instruments which are the hardest acquire the keenest edge and are the most capable of cutting; but then a great degree of hardness always occasions the metal to be brittle; and when the edge is very fine, such instruments are useless for dividing hard substances, because the sharp part is not tenacious enough to endure the operation without snapping asunder. It is necessary therefore to be content with less hardness in order to obtain the requisite tenacity, and this is effected by the operation called *tempering*.

Hence, when an instrument has been properly hardened, it must be softened again in some measure, or to that degree which is thought to be most

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[60] See *L'Art de convertir le Fer en Acier*, par M. Reaumur, page 359.

[61] Chalmers, vol. xxvi. pages 93, 94.

suitable for that particular purpose for which it is intended. To effect this, it is heated again only to a certain point, which is usually determined by the colour which the metal assumes, and then it is instantly plunged into cold water. This is called letting it down to the proper temper.

In France it has been the practice, in hardening small steel instruments, to cover them with soft soap and then to roll them in common salt. This treatment prevents the articles from scaling, and does not prevent the hardening. The salt fluxes to a glass which covers the metal and protects it from oxidizement[62].

Pliny informs us, that in his time the more delicate iron instruments were steeped in oil to quench them, lest they should grow too hard and brittle with water[63]. On the contrary, Jonston says that "if iron be plunged in vinegar it will endure no hammering, but will sooner break than draw[64]." The Lacedæmonians, who made their coins of iron rods, were used to steep them in vinegar when red hot, that, being thus rendered brittle, they might never be put to any other use[65].

Mr. Rhodes, an eminent cutler of Sheffield, has published some very important observations on the process of hardening steel. "Articles manufactured of steel for the purposes of cutting," says Mr.

[62] Berthoud's *Treatise on Marine Clocks*. Quarto, Paris 1773.
[63] Pliny, lib. xxxiv. cap. 14.
[64] Jonston's *History of the Things of Nature*, page 123.
[65] Plutarch. in *Vita Lycurgi*.

Rhodes, "are, almost without an exception, hardened from the anvil; in other words, they are taken from the forger to the hardener without undergoing any intermediate process; and such is the accustomed routine, that the mischief it contains has escaped observation. The act of forging produces a strong scale or coating, which is spread over the whole of the blade; and, to make the evil still more formidable, this scale or coating is unequal in substance, varying in proportion to the degree of heat communicated to the steel in forging; it is, partially, almost impenetrable to the action of water when immersed for the purpose of hardening. Hence it is that different degrees of hardness prevail in nearly every razor manufactured: this is evidently a positive defect; and so long as it continues to exist, great difference of temperature must exist likewise."

"Razor-blades not unfrequently exhibit the fact here stated in a very striking manner: what are termed clouds, or parts of unequal polish, derive their origin from this cause; and clearly and distinctly, or rather *distinctly* though not *clearly*, show how far this partial coating has extended, and where the action of the water has been yielded to, and where resisted. It certainly cannot be matter of astonishment, that so few improvements have been made in the hardening of steel, when the evil here complained of so universally obtains, as almost to warrant the supposition that no attempt has ever been made to remove it. The remedy, how-

ever, is easy and simple in the extreme, and so evidently efficient in its application, that it cannot but excite surprise, that, in the present highly improved state of our manufactures, such a communication should be made as a discovery entirely new.

"Instead of the customary mode of hardening the blade from the anvil, let it be passed immediately from the hands of the forger to the grinder; a slight application of the stone will remove the whole of the scale or coating, and the razor will then be properly prepared to undergo the operation of hardening with advantage. It will be easily ascertained, that steel in this state heats in the fire with greater regularity, and that when immersed, the obstacles being removed to the immediate action of the water on the body of the steel, the latter becomes equally hard from one extremity to the other. To this may be added, that, as *the lowest possible heat at which steel becomes hard is indubitably the best*, the mode here recommended will be found the only one by which the process of hardening can be effected with a less portion of fire than is, or can be, required in any other way."—"These observations are decisive, and will, in all probability, tend to establish in general use what cannot but be regarded as a very important improvement in the manufacturing of edged steel instruments[66]."

It has always been difficult to explain how the

[66] See an *Essay on the Manufacture of a Razor*, by E. Rhodes, cutler, Sheffield, octavo, page 20.

water acts in hardening iron and steel; it is a subject that has ever been involved in obscurity, and I do not recollect to have seen any plausible conjecture or theoretical view offered upon it.

It is well known that the hotter any piece of iron is made and the more quickly it is cooled, the harder it will become in its texture. May this not be owing to the loss of its *latent* heat? When the metal is heated, its latent caloric probably becomes *free* caloric, and, by being suddenly plunged into cold water, it cools so rapidly that it has not time to combine with the matter of heat so as to fix it in a latent state. This seems the more probable, because it is generally allowed that iron and steel owe their malleability to their latent heat[67].

This, which at present is a mere speculation, may perhaps deserve investigation, and, by way of prosecuting the inquiry, I should propose the following experiment. Let two bars of iron be heated equally; cool one of them quickly and the other slowly, and then notice what difference there is in the time required to make each of them hot by the mere act of hammering them upon an anvil; for, I presume the bar which possesses the most latent caloric will the soonest be heated to any given degree of temperature by this operation; in which, however, the weight of the hammer, the frequency

[67] The philosophical reader will understand what is meant by the terms *sensible* and *latent* heat. Those who are not aware of the different states in which the matter of heat exists in bodies may be referred to Chap. III. of The Chemical Catechism.

of the strokes and their number, with all other circumstances, should be equal, in order for the result of the experiment to be accurate.

But, whatever may be the fate of this experiment, I am desirous, before we proceed with the subject, to make one observation on the property which iron possesses, almost exclusively, of acquiring various degrees of hardness and of becoming soft again at any time, as occasion may require.

It should be remembered, however, that steel differs from iron in this circumstance,—that if it be made red-hot and then immediately plunged into cold water, it becomes much harder than it is possible to make iron by such treatment. It may however at any time hereafter be softened again, merely by heating it afresh and then allowing it to cool gradually.

The property which iron and platinum possess of welding is very important, as has before been remarked; but were it not for this singular quality in iron, of being hardened and softened at pleasure, and which seems to me to be a striking and peculiar adaptation of a material to the uses for which it was originally designed, none of the arts dependent upon the uses of this metal could have been brought to the perfection which they have now attained; and if it were possible for iron and steel to lose this property of becoming hard and soft, such arts, however complete they may now be, would be lost with it.

I recollect having been very forcibly impressed with this idea when I first visited a manufactory of printers' types [68]. There the largest steel punches which are employed in making the brass moulds for receiving the type-metal, and some of these are very heavy, are all formed by other punches; and the largest and deepest letters are cut out in this manner, by main force. As these tools of steel are not hardened till they are completely formed by others that are already hardened, the latter cut out the former with as little difficulty, to all appearance, as if they were operating upon a piece of tin or lead; and yet these same articles, which are cut with so much ease, require only to be submitted to the hardening process, and then they will be as capable of operating upon soft iron or steel, and of cutting either of them as readily into any shape, as they were themselves cut when in their original state of native steel.

Here I should be guilty of great injustice if I were to omit to notice the improvements in softening and hardening iron and steel which have been discovered by Messrs. Perkins and Fairman of London, and employed by them in preparing steel plates on which they engrave bankers' notes. The methods are kept secret; but Mr. Brande has published a very curious and interesting account of what the inven-

[68] A full account of the method of making printers' types will be found in the fifteenth volume of Rees's *Cyclopædia*, article "Foundry."

tors have been enabled to do by these means, accompanied by a most beautiful specimen [69].

In the manufacture of edge tools the most important process, as was before mentioned, is that of tempering. But, to effect this in the best manner possible, there must be, as Mr. Nicholson [70] has happily expressed it, "a precise mean between too "soft and too brittle, which will be best suited for "the respective purposes to be accomplished. A "spring must be tenacious, and need not be very "hard. A knife for cutting leather and other soft "substances, must be somewhat harder than a "spring. Penknives and razors must be still "harder; and files and tools for working metal "must be hardest of all; though, even in these, "care must be taken not to destroy their tenacity "by making them too hard."

Hence it will be apparent that great nicety must always be observed in the operation of tempering; and if due care be not taken, there can be but little chance of the instruments ever fulfilling the respective purposes for which they are designed. The temper of a lancet is generally the highest of any polished steel instrument, and therefore it is merely owing to its being so very thin that it springs a little at the extreme point.

The usual mode of ascertaining the temperature to which any edge tool has arrived, is by attending

[69] The *Quarterly Journal of Science*, vol. ix. page 124.
[70] Nicholson's Quarto *Journal*, vol. i. page 381.

during the operation to the shades of *colour*, which, as the metal becomes more and more heated, the bright parts assume in rotation, and then when it has acquired that particular hue which may be desired, removing it from the fire into water. But the nature of the operation is such, that this must always be attended with some uncertainty, especially as different tools require different management in the process, and it is often a very uncertain task to give the same temperature to every part of the same instrument.

It was on account of these and some other difficulties which the makers of edge tools constantly labour under, that I was induced to turn my attention to the subject, trusting that I should be enabled to suggest to the unscientific cutler, some improvement in this most important though very uncertain branch of the art. But, in order that the reader may be better able to appreciate what I have to propose, I shall first show what particular colours are usually required for the tempering of a few of the instruments which are most in demand, and then explain some of the methods now practised for the attainment of some peculiar purposes.

This detail of the gradation of colours, I have copied from Mr. Nicholson's account of some experiments by Mr. Stodart [71], and from Mr. Aikin: but the opinions of scientific men on the cause of these variations of colour, have been very different;

[71] Nicholson's Quarto *Journal*, vol. iv. page 129.

and in my opinion all of them are very unsatisfactory. Sir Isaac Newton supposed that the size of the metallic particles must have been altered by the action of the fire. Later writers have attributed these changes to the different degrees of oxidizement which the steel undergoes; and M. Prieur has endeavoured to account for them by supposing that they are occasioned by an alteration in the arrangement of the particles, and that the colours are apparently in concentric rings. This he has endeavoured to explain by the feathers of the peacock, the neck of the pigeon, the duck's wing, &c. [72]

In tempering edge tools the first colour, which appears at 430° of Fahrenheit, is very pale and only a little inclining to the *yellow*; this is the temperature at which lancets are usually tempered.

At a little higher temperature, say 450°, the pale *straw* colour appears, which is a heat suitable for the best razors and most of the surgical instruments. Then comes the *full yellow*, at 470°, which is proper for common razors, penknives, and some other implements of surgery.

By increasing the temperature to 490° the *brown* colour will be produced, which is generally looked for by those who have to temper garden-hoes [73], small shears, and scissars, and all those chisels which are designed for cutting *cold* iron. Then at 510°

[72] *Annales de Chimie*, tome lxi. page 154—179.

[73] Some workmen prefer 460° or 470° for garden-hoes and such like implements.

comes the brown, dappled with *purple spots*, which shows the proper heat for tempering axes, firmer-chisels, plane-irons, and pocket-knives. The next colour in succession is the *purple*, at 530°, the heat at which table-knives and large shears are usually tempered. The next is the *bright blue*, at 550°, which will give a proper temper to swords, watch-springs, springs for trusses, bell-springs, &c. Then comes the *full blue*, at 560°, which being the highest spring temper is usually employed for small fine saws, daggers, augers, &c. This is the proper heat also for tempering most of those instruments which require to be elastic. The last degree in succession is the *dark blue* approaching to black, which shows itself at 600°, and is the softest of all the gradations of temper, when the metal becomes suitable to few other instruments than hand and pit saws, which are necessarily made very soft in the first instance, that the workmen may be able to file them up and set them whenever they find occasion for it, without being obliged to soften them every time that operation is to be performed. This great heat is likewise employed in tempering some particular kinds of springs.

Some curious facts respecting the properties of *blued* steel are related by Mr. Nicholson on the testimony of Mr. Stodart, who says "that he has found the spring or elasticity of the steel to be greatly impaired by taking off the blue with sand-paper or otherwise; and, what is still more striking, that it may be restored again by the blueing process, with-

out any previous hardening or other additional treatment [74]."

Extraordinary as these facts may appear, they have been fully confirmed by a manufacturer of Sheffield, who signs T. B. (probably Mr. Boulsover) and who writes thus:—"I took," says he, "a steel plate 30 inches long, 12 broad, and about ,04 thick; I hardened it in a composition of oil and tallow, and afterwards tempered it down to a spring temper; it was now so elastic as to recover its position after being bended—by hammering it to set it straight, it lost a part of its elasticity; after being ground in the same manner as a saw, the elasticity became still less, having nearly returned to the same state as before hardened:—it was then very uniformly heated until it became blue; it now recovered the whole of its elasticity:—after being glazed bright upon a glazier coated with emery, the elasticity was found to be impaired, but in a less degree than when it was ground;—the same effect was also produced by rubbing with emery or sand-paper, and also by burnishing; invariably the elasticity was recovered by blueing, and hence this is always the last operation in the manufacture of elastic steel plate [75]."

Every maker of edge tools well knows that their temper is indicated by the colour which they assume; thus by observing the progress of the colours, he is guided in operating on the different

[74] Nicholson's *Journal*, vol. xii. page 63.
[75] Ibid. vol. xiv. page 266.

kinds of instruments, experience alone being the rule in these cases; but in order to obtain the most favourable results in some instances of nicety, there are other minutiæ which require much care and observation.

Thus, in tempering penknives and other tools which have a *thick* back and a very *fine* edge, they are always laid with the backs downwards, either in heated sand or on a hot iron plate; otherwise they would become too soft at the edge, before the backs could be entirely heated.

In hardening knife blades it is usual to plunge them perpendicularly into the water, to prevent their warping by being cooled with too great rapidity. And here it may be remarked, that if steel be heated only to that point when it begins to become red in the dark, and then plunged into cold water, such metal will not become hard. The heat for hardening must indeed be so great, that in winter the workman is obliged to take the chill off the water before the goods are immersed in it, to prevent them from cracking by the suddenness of the transition. Mr. Stodart says that one of his workmen makes up his charcoal fire with shavings of *leather*, finding that this is effectual in preventing the tools from cracking by this process [76].

For the best methods of preventing the warping of steel instruments in the operation of hardening, a paper by Mr. E Lydiatt may be consulted with

[76] Nicholson's Quarto *Journal*, vol. iv. page 128.

advantage; there are few cutlers who could not derive some valuable information from its perusal [17].

For hardening very small instruments various other schemes have been adopted. Thus, fine drills and small gravers are hardened by heating them with a blow-pipe over a candle, and then running them instantly into the body of the same candle. In this way only one instrument can be hardened at a time; and as such minute tools would be cooled too much before they could possibly be immersed in water, this expedient has been adopted, and succeeds sufficiently.

Formerly some cutlers employed suet, oil, solutions of sal-ammoniac and other salts for immersing the heated goods into in the process of hardening; but these methods are now, I believe, all abandoned. Mr. Nicholson has stated that "Mr. Stodart has not found that any advantage is obtained from the use of salt in the water," though he adds that "questions respecting the fluid to be used in hardening are, properly speaking, applicable only to files, gravers, and such tools as are intended to be left at the extreme of hardness[18]." It was found, indeed, that oil had an injurious effect, and that such cutting-instruments as had been hardened by being plunged into cold oil would never take a fine edge.

I know, however, an artist who makes a large quantity of truss and other springs, and who has very

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[17] See Nicholson's *Journal*, vol. xxxiv. page 31.

[18] Nicholson's Quarto *Journal*, vol. iv. page 128.

ingeniously taken advantage of this property which oil has of giving steel a coarse grain. He conceived that if the steel were less compact than usual, such springs would have greater elasticity; and this he has long found to be the fact: he therefore now hardens all his springs by heating them till they acquire the full blue colour, and then plunges them into a vessel of cold linseed oil.

Saw-makers temper their goods in a different way. They rub them over with suet or other grease, and then heat them gradually until the temperature of each tool is raised sufficiently to set fire to the grease of itself, and occasion it to blaze. By this means they are thought to acquire a temper equal to what would be obtained by heating them in the usual way till they became of a deep blue. The operation is called *blazing*. The great manufactory of saws is at Sheffield, and there this practice is observed. It usually brings the article to the temperature of about 600° of Fahrenheit.

Mr. Hardy, a skilful artist, who has written on the construction of Time-pieces, says "that the saw-makers first harden their plates in the usual manner, in which state they are more or less contorted or warped, and are brittle,—that they then blaze them; which process deprives them of all springiness, so that they may be bended and hammered quite flat, which is a delicate part of the art of saw-making;—and that they blue them on a hot iron, which renders them stiff and springy without altering the flatness of their surface." He adds that "soft un-

hardened steel may be rendered more elastic by blueing, and that hard steel is more expansible by heat than soft[79]."

I know of no instruments, however, which require so great nicety in hardening, as the files which are intended for sharpening carpenters' hand-saws. The saws themselves being made of cast-steel are extremely hard, and therefore the file must be still harder before it can make any impression upon them. But there is a difficulty attending this process, namely, that if these small instruments be made any harder than is absolutely necessary, they become brittle, and their teeth will be liable to fly at every stroke. I mention this, because I consider that a method of bringing these small tools to a proper temper, *with certainty*, is an object well worth the pursuit of persevering and ingenious men.

In file-making, the great desideratum is to unite tenacity with hardness. If steel for this particular purpose were made with *animal* instead of *vegetable* charcoal, this excellence might probably be attained.

It is rather a digression from the subject of hardening steel instruments, but it may be acceptable to several of my readers to mention, that Mr. G. Cumberland of Bristol has recommended the making of large files with a compound of clay and ground silica, and, when they become sufficiently dry, to form the teeth by the pressure of muslin of various degrees of fineness; after which they are to be burnt,

[79] Nicholson's *Journal*, vol. xii. page 63.

to bring them to the hardness of the best stone-ware[80]. Such tools might be made much cheaper than the commonest steel files, and for many purposes that might be mentioned they would be of great utility.

In visiting a manufactory of files, I could not avoid noticing an expedient which the workmen adopt in the process of hardening that instrument, and which is, perhaps, as perfect and efficient as any they could have been directed to by the most correct knowledge of chemical science, though it was doubtless the mere result of accident and observation, without the aid of any theory whatever.

Some of the large files are very thick, and require to be submitted to an intense heat in order to give them the requisite degree of hardness; and yet the teeth of these instruments are sometimes so delicate, that the action of the fire, aided by that of the atmosphere, would, if they were unprotected, be quite sufficient to convert them at one heat to a crumbling oxide, and of course to render the tool useless. These manufacturers therefore make a mixture of common salt and powdered bone-ash with grounds or settlings of ale; and when these become of a proper consistence, each file is completely covered with it before it is thrust into the body of the fire.

When first covered with this preparation, they are laid one by one at some distance above the fire,

[80] Nicholson's Octavo *Journal*, vol. xxv. page 257.

and across some slight bars of iron fixed within the brick-work on purpose to receive them. Here they acquire a sufficient degree of heat just to bake on the mixture, and harden it so as to prevent its removal by the friction of the coals as it is put into the fire-place. When this is properly baked on, they are heated red-hot, and immediately plunged into cold water, or some other fluid, to complete the hardening process. This is done rather slowly, and at the same time care is taken to introduce them into the water in a perpendicular position, which is necessary to prevent these instruments from warping by the sudden transition. Diluted sulphuric acid was formerly employed for this purpose, it being imagined that it rendered the files harder; but this has lately been given up, and recourse is now generally had to coldwater only. Reaumur recommends aqua-fortis for this purpose [81], as before mentioned; but I apprehend it is not better than cold water alone.

Though the mode just described may be perfect, the composition of the article with which the files are covered may perhaps be still improved. Thus, several artists mix some *animal* substance with the saline compound, and this is likely to be a considerable improvement. On the contrary, some file-makers use common flour instead of bone-ash, and mix it with the saturated solution of salt till the whole acquires the consistence of treacle. There is

[81] *L'Art de convertir le Fer en Acier*, page 359.

an advantage in this mixture, namely, that a mere single immersion of the files in it is sufficient to coat them entirely, and perfectly protect them from oxidizement.

I had forgotten to mention, that when these instruments have been tempered in the manner already described. they are well washed in water, and then brushed with dry coke-dust, which makes them quite clean, and gives them a considerable degree of brightness.

It has been recommended to make files for some particular trades, with iron, and then to case-harden their surfaces, because such files would bend, and hence might be made useful for many purposes to which common steel files cannot well be applied. This method of preserving the teeth of files and rasps while tempering, is described, under the idea that a general knowledge of it might perhaps furnish some useful hints respecting the preservation of metals, especially iron, from oxidizement during the progress of this and other similar processes in the arts.

From these few observations the reader may conceive, that the discovery of some certain and infallible mode of imparting any specific degree of heat to iron or steel, that may be necessary for the processes of hardening and tempering, must be an important desideratum in the manufactory of edge tools.

In the year 1789 Mr. David Hartley took out a patent for a method of tempering steel by the aid

of a pyrometer or thermometer applied near to the surface of the article, and at the same time recommended the use of heated oil, in which he says many dozens of razors or other tools might be tempered at once with the utmost facility, and the various degrees of heat necessary for the different purposes might speedily be determined by experiment[88].

When I first saw this announced in the public journals, it immediately occurred to me that the principle might be improved upon, and if a bath of oil, or of some kind of fusible metal, were contrived for the tempering of every species of edge tool, that a greater degree of certainty would be given to this operation, than the persons who have generally the conduct of such manufactories have ever experienced.

Influenced by these views of the subject, I determined long ago, that I would embrace some opportunity of instituting a series of experiments, to determine at what degrees of temperature all the common kinds of oil enter into ebullition, and also the melting points of several metallic compounds, in order to be able to furnish the practical cutler with a few tables, from whence he might learn how to construct a bath in which he could at all times impart the desired temper to the particular instruments of his manufacture, with the utmost certainty and with unusual dispatch. These experiments have been performed, and those results which were deemed most important will be given in a tabular form in the Appendix to this volume.

[88] Mr. Nicholson has given some account of this patent in the first volume of his Quarto *Journal*, page 382.

In the application of this principle of tempering edge tools in a fluid menstruum, whether metallic or otherwise, it will be advisable to have the bath which is to contain the heated fluid, made of cast-iron, which should vary in form and size so as to adapt it to the particular sort of tools or instruments which are to be tempered within it. And where the business is considerable, it would be convenient to have two such baths fixed in brickwork, adjoining to each other and heated by the same fire, with registers to cut off the communication of either of them with the fire-place at pleasure, so that one might be heating while the workman was tempering his goods in the other.

Many advantages would result from this method of tempering edge tools. In the first place, there could never be any uncertainty as to the degree of temper which the articles would acquire; for, when the manufacturer had once ascertained which of the metallic baths was suitable for any particular kind of edge tool, all that would be necessary would be to arrange the goods in rows upon the surface of the congealed metal, to light a fire underneath the containing vessel, and then carefully to observe when the surface of the fusible metal begins to melt. As soon as this takes place, the edge tools are immediately to be removed and plunged into cold water, by which means the whole parcel will have acquired exactly the same temper.

Secondly, where instruments have a thick back and a fine edge, it is almost impossible ever to give them an uniform temper by the old method; for

there will always be a danger of the edge being lowered too much before the other parts become regularly heated throughout. This difficulty occurs particularly in razors, where the thickness of the back is always a formidable obstacle to the attainment of an uniform regularity of hardness. It may however be determined by means of nitric acid, whether a razor or other polished edge tool be of an equal degree of hardness: for, on applying this acid to bright steel, the black tinge will appear more speedily and strongly upon the hard parts than on the rest of the surface[84]. The inconvenience attendant on the manufacture of this particular instrument has been so great, that Messrs. Rhodes and Champion, eminent cutlers of Sheffield, have invented what they call the "New frame-bladed Razor," in which the back and the finger-hold are made with an alloy of copper, not subject to rust, and the blade only is made with steel. These blades being nearly as thin at the back as at the edge, they can be tempered without incurring the danger already mentioned; and when one of these is let into the copper back, it becomes a complete instrument. This however is attended with a considerable additional expense, which would be unnecessary if the plan of the metallic bath be adopted.

In the hardening of large files and rasps, which require to lie a considerable time in the fire before they become heated throughout, this expedient

[84] Nicholson's Quarto *Journal*, vol. iv. page 131.

would be of incalculable advantage; indeed, I know of no instrument, except the scythe, and the pit-saw, which might not be tempered with more certainty by means of a fluid bath than by the process in common use. And there is no reason for excepting these but their great size, which would render the tempering of them in metallic baths both troublesome and expensive.

When the sword was the chief weapon of war, it must, as Mr. Nicholson has observed, have been an object of great interest and demand to give to its blade a durable keen edge, and a degree of firmness or strength, which, without rendering it unwieldy, should ensure the warrior against exposure to the fatal accident of its breaking in the act of combat.

Formerly, no man in Great Britain knew how to temper a sword in such a way that it would bend for the point to touch the heel and spring back again uninjured, except one Andrew Ferrara, who resided in the Highlands of Scotland. The demand which this man had for his swords was so great that he employed workmen to forge them, and spent all his own time in tempering them; and found it necessary, even in the day-time, to work in a dark cellar, that he might be better able to observe the progress of the heat, and that the darkness of his workshop might favour him in the nicety of the operation. Had this ingenious artist thought of a bath of oil, he might have heated this by means of a furnace underneath it, and by the use of a thermometer, to

the exact point which he found necessary; though it is inconvenient to have to employ a thermometer for every distinct operation. Or, if he had been in possession of a proper bath of fusible metal, he would have attained the necessary certainty in his process, and need not have immured himself in a subterranean apartment.

The swords which were formerly in the highest repute, were made at Damascus in Syria. The method by which these were made, has long been lost; or perhaps it was never thoroughly known to Europeans; but it is supposed that they were formed by alternate layers of extremely thin plates of iron and steel bound together with iron-wire, and then firmly cemented together by welding. These weapons never broke, even in the hardest conflict, and yet they retained so powerful an edge, that the armour made like net-work with scales of iron, or with small iron rings, called coats of mail, was instantly divided under their force.

This manufactory at Damascus had formerly the greatest reputation throughout Europe and through a great part of Asia; but in the latter end of the fourteenth, or at the beginning of the fifteenth century, Timour Bec, usually called Tamerlane, on his conquest of Syria [84], carried away all the best workers in steel from Damascus to Persia; and we know

[84] Gibbon's *History of the Decline and Fall of the Roman Empire*, vol. xii. pages 21 and 45.

so little of Persia, that it may be difficult now to ascertain whether this peculiar manufactory is still carried on in that country or not.

A writer in Nicholson's Journal, who had the opportunity of examining a real Damascus blade, which had cost the possessor twelve guineas at Constantinople, has thus described it: "It had (says he) a dull grey or blueish appearance, was scarcely harder than common steel from the forge, was not easily bended, and when bended had no spring to recover its figure. Its back was smooth, as were also two narrow sloped surfaces which formed its edge under an angle of about 40 degrees; but its flat sides were every where covered with minute waving lines in masses in all directions, not crossing each other, and, for the most part, running in the direction of its length. The lines were in general as fine as harpsichord wire, not extremely well defined nor continued; and their distinction from each other was effected by no perceptible indentation of the surface, but rather by the succession of parts differing in the degree of polish or brightness."

"I was informed," says the writer of the memoir, "that if any part of this blade were made smooth by grinding or whetting, the wavy appearance, called the water, could be again produced by means of lemon juice; and that its excellencies were, that it could be depended upon not to break; and that it would cut deeper into a soft substance, such as a pack of wool, or into flesh, than any other kind of sword blade."

"I infer therefore," adds the writer, "that the Damascus steel is in fact a mechanical mixture of steel and iron; that it is incapable of any considerable degree of hardness, and consequently is in no danger of breaking from its brittleness; that its tenacity is ensured not only from the admixture of iron, but likewise from the facility with which its soundness may be ascertained throughout, by the same process which exhibits the water or fibrous appearance; and, lastly, that the edge of a weapon formed of this material must be rough, on account of the different resistance which the two substances afford to the grindstone, in consequence of which it will operate as a saw, and more readily cut through yielding substances than such cutting tools as are formed of a more uniform substance [85]."

The conjectures of this writer respecting the methods by which these blades were manufactured at Damascus, and the account of the experiments which he himself undertook for the purpose of enabling him to imitate them, are extremely interesting and instructive, so much so that I have no hesitation in recommending the whole paper to the perusal of all those who are curious in the manufacture of edge tools.

The account of an experiment by Mr. Stodart for imitating the Damascus blades may be seen in Nicholson's octavo Journal, vol. vii. page 120. A paper by Mr. Troughton on the expansion of steel will be found in the same work, vol. ix. page 230.

[85] Nicholson's Quarto *Journal*, vol. i. pages 468—471.

I would not have it understood that I wish to lay any claim to the merit of the discovery of metallic baths for the tempering of edge tools, because I know of two or three individuals who, for some particular articles, have for several years adopted this expedient; but I have reason to believe that the few cutlers who have been in the habit of tempering in a fluid bath, have always employed a thermometer; whereas the object of my experiments is to furnish a list of baths, either of which may be used with certainty, without employing that instrument. Moreover, as the practice is very much confined, and few workmen, comparatively, have any idea that it would be possible to render such a method available, I was desirous of explaining its principles, and of furnishing a scale by which the manufacturer might acquire the means of tempering any instrument whatever, in such a manner as will render it entirely suitable to the purpose for which it is intended.

It has also occurred to me, that by numbering the different baths in a regular gradation, the workman will never have any thing respecting the process to charge his memory with, except the recollection of the *number* of the bath which he will have to employ for his own particular purpose. But what has been offered on this subject must suffice, as I have some other observations to make before I conclude this Essay.

"It is a generally prevailing opinion," says Mr. Rhodes, "amongst men accustomed to the process "of hardening steel, that if it be overheated pre-

" viously to immersion, an extra portion of heat is " likewise required to reduce it, or what is termed " *let it down*, to a proper degree of hardness; and " that without this a good cutting edge cannot " possibly be produced. This, indeed, to say the " least of it, is a miserable and ineffectual attempt " to remedy one error by the introduction of an- " other. That this is an extremely injurious opi- " nion, and that it operates perhaps more than any " other cause whatever, to produce a mass of infe- " rior cutlery, must be obvious to every one who " thinks at all upon the subject.

" It may be laid down as a position, which is not " in much danger of being controverted, that *the* " *lowest possible heat at which steel becomes hard* " *is indubitably the best*; and that to impart to it " any extra portion, is essentially to affect its most " valuable properties. If over-heated, the pores of " steel become open and expanded, the fineness of " its texture is annihilated, and it is rendered so " extremely susceptible of injury from the influ- " ence of heat, that a small portion acting upon it, " when it is in this state, entirely destroys its ca- " pability of sustaining a cutting edge.

" It must not be inferred from these remarks, " that any degree of temper whatever will operate " to restore to steel the pure properties of which it " has been deprived by being over-heated. Work- " men, however, acting under the influence of the " preposterous opinion here deprecated, manifest " great carelessness in the performance of this very

" critical operation, always imagining the evil ef-
" fects of this carelessness may be remedied by re-
" sorting to a practice most palpably erroneous [86]."

From the information which I have collected in various quarters, I am inclined to think that the bad temper of many of our small edge tools may be attributed to improper management in tilting the steel; I therefore, on a late journey to the north of England, embraced that opportunity of visiting the public forge which is employed by most of the cutlers in the town of Sheffield, and where these manufacturers send their steel to be drawn out into bars of different forms and of different sizes, according to the various purposes for which it is intended. I observed that the process of tilting, or drawing out into fine bars, is conducted in the following manner.

The steel, which is usually in bars of 2¼ inches square and about 2½ feet long, is put, several bars together, into a wind furnace, that it may be sufficiently softened by heat to render it quite ductile under the forge hammer. This hammer, which is very weighty, is moved by a water-wheel, and strikes incessantly upon an anvil fixed immediately beneath it. By means of this apparatus the heated bars may be drawn down to any size which the manufacturer requires; and one man and a boy are all the hands which are necessary for performing the work.

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[86] An *Essay on the Manufacture of a Razor*. By E. Rhodes. Sheffield, octavo, 1809, p. 18.

To conduct this operation the man seats himself in a *hanging* wooden seat, very similar in appearance to one of the wooden planks suspended to a pair of large scales, and which is fixed to the ceiling by four strong iron wires, in such a position as to swing directly opposite to the anvil on which the steel is to be laid and drawn into bars.

When the man has properly fixed himself in this seat, the boy brings him one of the heated bars and slides it under the forge hammer. The workman immediately takes charge of it, and moves it a little either backwards or forwards according to his judgement, every time the hammer rises, so that every part of the metal in its turn may be uniformly submitted to the action of the forge hammer. By this repeated hammering the steel is soon drawn very considerably thinner; and when the workman finds that it is becoming too cold for the forging to make the proper impression upon it, it is once more or oftener heated in the furnace, and as often submitted to the action of the tilting hammer, until it be reduced to the desired size and shape.

As only one extremity of the bar is at first submitted to the action of the hammer, and as it is necessary to slide it gradually further and further underneath it, the workman is under the necessity of approaching nearer to the anvil or of receding from it, every time the hammer rises or falls. To enable him therefore to do this with facility, there is a small well of about a foot deep, sunk within the floor for the reception of his legs, and directly under

that part of the ceiling to which his seat is suspended. Things being thus arranged, the operator is enabled by a slight motion of his foot, and without any painful exertion, to move himself either backwards or forwards as his work requires.

While I attended this operation, I observed that very different degrees of heat were given to the strong bars in order to soften them for the tilt hammer; and I can readily conceive that the injury which I have spoken of as being done to bar-steel at the tilting-house, may be entirely attributed to this circumstance—the unequal or superfluous application of heat.

I observed, also, that those bars which were unnecessarily heated, threw off a prodigious number of thin scales at every blow of the hammer; and when I made inquiry respecting this, I was informed that the manufacturers generally expect that the steel which they send to this establishment will lose five per cent. in weight by the operation of tilting; and that when the bars are heated more than necessary, this loss is always proportionably greater. The charge usually made for drawing steel into fine bars, is from 5*s.* to 6*s.* 6*d.* per cwt. according to the size required.

After I had visited this public forge and witnessed the carelessness with which the bar-steel is heated, I felt extremely desirous of ascertaining the degree of effect produced on cast-steel by being brought to too high a temperature, not doubting that the badness of many of our edge tools might be chiefly

ascribed to this cause. Therefore, before I left Sheffield, I procured a small bar of cast-steel, and having borrowed the use of a hearth, I made the following experiment.

The bar of steel was first broken into three pretty equal parts; I then heated one of these to a low red heat, and immediately cooled it by sinking it very gradually into a trough of cold water. The second was heated considerably more, even to a full red, and cooled in the same manner. The third was brought to an intense white heat, and then instantly quenched in cold water, like the preceding parts.

Afterwards, on breaking a small piece from one end of each of these bars, the following appearances presented themselves, which completely satisfied me of the decisive nature of the experiment. The first exhibited a very fine, close, and compact grain; the second was of a much coarser texture; and the grain of the third was analogous in all respects, and quite as coarse as that of a piece of common cast-iron.

It is well known that cast-steel is brittle and useless before it be tilted, or drawn out by the forge-hammer; but if it be heated too much for this operation, the texture of the metal will be so much altered by this excess that it will be rendered entirely unfit for the fabrication of fine instruments. It may here however be mentioned, that such steel as will suit one implement is often not fit for another. That which has the most blisters is generally the

hardest and fittest for files, &c.; but the softest steel, or that which approaches the nearest to the state of wrought iron, is most suitable for many other purposes.

There is another circumstance which militates very much against the perfection of the finer sort of edge tools, namely, the velocity that is given to the motion of the stones on which the instruments are usually ground and polished. The workmen at Sheffield are not paid for their time, but by the piece, or according to the quantity of work finished; it is consequently their interest to use the utmost dispatch, and urge the grinding-stones to the most rapid motion, because the amount of the work will, in fact, be in proportion to the celerity of the revolving stones.

At Sheffield the stones are usually moved either by a steam-engine or a powerful water-wheel; therefore any degree of velocity may be given to them, by simply moving the strap to a pulley of a larger or smaller diameter. This indeed has sometimes been pushed to such an extent, that the stones, merely by the centrifugal force which they had thus acquired, have been dashed into innumerable pieces, and have occasioned the death of the workmen and by-standers.

Those who have paid attention to the process of tempering steel will readily conceive the great injury that a fine edge tool is likely to suffer from the

accumulated heat occasioned by a revolving grindstone, or other rough mineral substance in rapid motion. This is an evil of great magnitude; but unless men of real principle be found who would willingly engage in this employment, and be content that their own interests should be subservient to that of their master, and that their first aim be to give perfection to the quality of the goods they fabricate, I am afraid that no effectual remedy can be adopted.

In a late voluminous and very respectable publication it is said, that the *Wickersley* stone is usually employed for grinding edge tools, because this stone has the peculiar property of not heating to a great degree any substance ground upon it. This appeared to me to be so very extraordinary that I determined to make an inquiry, on my next journey into Yorkshire, respecting this circumstance. I have since however been assured by some of the most extensive cutlers at Sheffield, that the assertion is without foundation, and that there are other reasons for the preference which is often given to this particular stone.

Wickersley is a village situated between Rotheram and Doncaster, about ten miles north-east of Sheffield. From the inquiries which I have made, I learn that this stone, which is of a light-buff colour, with a slight shade of red intermingled, is used for grinding all the fine hard steel goods, such as razors, penknives, and the best scissars; and it is preferred for these, not because it produces a less

degree of heat in the operation [87], but from the fineness of its texture, from the rapidity with which it cuts, and from its not being subject to have hard or knotty places interspersed in it, an imperfection to which most other grindstones are liable. The workmen in general give the preference to these stones for articles made with hard steel; but soft or unhardened goods, such as fork-shanks, for example, are usually ground with a stone which possesses a much greater degree of hardness.

In the Supplement to the *Encyclopedia Britannica*, article CUTLERY, mention is made of a green stone found in some parts of the old pavement of London, as the only known material capable of giving to lancets the smooth edge which they require. This stone, which is now extremely rare and valuable, is a soft hornstone. Its analysis has been published by Mr. Faraday [88].

Another kind of edge tool remains to be described, which is made of *cast-iron* and afterwards converted into steel. The method of conducting this process was discovered by Mr. S. Lucas of Sheffield, and he has obtained a patent for the invention. In order that all classes of readers may be able to appreciate the merits of this very inge-

[87] It appears from a memoir by Mr. Nicholson, that hard tallow may be applied to grindstones with great advantage, for lessening the quantity of heat usually developed in the operation of grinding. He has explained its action on true chemical principles. See Quarto *Journal*, vol. i. page 131.

[88] See Mr. Brande's *Quarterly Journal*, vol. vii. page 400.

nious process, it will be necessary to explain what constitutes the difference in the various sorts of iron, and likewise in what respect this differs from steel.

Iron is found in the state of an ore in the bowels of the earth, and, in abstracting from this an useful metal, the first product is generally *cast-iron*, which owes its fusibility to the combination of carbon and oxygen[89]. This varies, however, in quality according to the quantity of carbon combined with it; and consequently such kinds are selected as are thought to suit the different purposes to which they are to be applied. That which contains the most carbon is chosen for small castings and for the neater kinds of ornamental work, while the harder metal, which has less carbon, is always preferred for railways, water-wheels, and all other large articles which are designed to sustain much wear.

It is necessary that the carbon be intimately united with the metal to form good pig-iron. This accounts for the preference which is always given to that iron which is made with wood-charcoal, for this enters more readily into combination with the iron than even the best mineral coke. When coke is employed in the process of making pig-iron, that which is the softest is always found to be the best, while the *hard* coke is selected for heating the blast furnaces.

Wrought iron is malleable though very infusible,

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[89] I doubt the presence of oxygen in cast-iron, it being incompatible with carbon in a high temperature.

and it acquires these changes in its properties by continued heat and repeated hammering, which deprive the metal in a great measure of the oxygen and carbon [90] which occasioned its great fusibility when in the state of *cast* iron. But it varies very much in its quality, according to the mode of its preparation, and the nature of the coke or charcoal which has been employed in its manufacture.

Steel differs from wrought as well as from cast iron, in having resumed a small portion of carbon, and likewise by containing a very minute proportion of silica and phosphorus [91]. Steel is a most important preparation of iron; for it possesses the malleability of wrought iron without its infusibility, and also has the fusibility of cast-iron without the brittleness of that substance. It completely unites the malleability of the one with the fusibility of the other. A particular account of the methods by which steel was usually prepared in the middle of the last century is given by Mr. Dossie in his Insti-

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[90] Mr. Mushet has published the following table of the proportions of carbon in the different kinds of iron and steel. See *Phil. Mag.* vol. xiii.

Soft cast steel	$\frac{1}{120}$
Common ditto	$\frac{1}{100}$
Ditto harder	$\frac{1}{90}$
Ditto too hard for drawing	$\frac{1}{50}$
White cast iron	$\frac{1}{25}$
Mottled ditto	$\frac{1}{20}$
Black ditto	$\frac{1}{15}$

[91] An account of the process of making *native* steel by the simple fusion of an iron ore found in Stiria, is given in the *Annales de Chimie*, tome xix. p. 18—29.

tutes[92]. Some account of the present modes of making both the blistered and the shear steel has already been given. Cast-steel, according to Mr. Aikin, is made by the following process:—

"The finest kind of steel, called *English cast steel*, is commonly prepared," says he, "by breaking to pieces the blistered steel, and then melting it in a crucible with a flux composed of carbonaceous and vitrifiable ingredients. The vitrifiable part of the mixture is of use only inasmuch as it is a fusible body, which flows over the surface of the metal in the crucibles, and prevents the access of the oxygen of the atmosphere. Broken glass is sometimes used for this purpose.

"When the metal is thoroughly fused, it is cast into ingots, which by gentle heating and careful hammering are tilted into bars. By this process the steel becomes more highly carbonized in proportion to the quantity of flux, and in consequence is more brittle and fusible than before. Hence it surpasses all other steel in uniformity of texture, hardness, and closeness of grain, and is the material employed in all the finest articles of English cutlery[93]."

Three or four years ago, Oostad Muhammed Ali described in the Laboratory of the Royal Institution of Great Britain the method of making cast-steel

[92] Dossie's *Institutes of Experimental Chemistry*, vol. ii. pages 375—388.

[93] Aikin's *Chemical Dictionary*, article *Iron*, vol. i. p. 602.

in Persia. The iron, he said, is brought from the mountains: a square place is built up, about four feet in the side, and five or six feet high, the walls eight or nine inches thick; stones of a slaty kind are placed in the inside about 18 inches from the bottom, so as to form a grate; below this is a chamber for the reception of the melted steel, and above it is placed the iron in bars, and charcoal intermingled together. There are three apertures above the grate into the furnace, into which air is propelled from bellows worked by men sitting; a fire is lighted, and the heat raised; fresh charcoal is thrown on as that in the furnace burns away; and as the iron becomes carbonized, it melts and falls through the grate as fluid cast-steel, into the chamber beneath, from whence it is taken and cast into ingots.

To prepare the cast-steel, three or four hundred weight of iron is placed in such a furnace, and there is a loss of about one-third from oxidation, and adhesion to the sides. The operation requires from two to three days, with constant blowing. M. Muhammed described the charcoal that was employed, as being exceedingly hard and heavy, and very unlike our charcoal, but did not know of what wood it was made *.

The invention by Mr. Lucas, of converting edge

* *Quarterly Journal of Science*. vol. viii. page 160.

tools made of cast-iron into good steel, appears to be an important improvement. It consists in stratifying the cast articles, in cylindrical metallic vessels, with native oxide of iron pulverized, or sand containing oxide of iron, and then submitting the whole to a regular heat in a furnace built for the purpose. It is not necessary that the oxide employed should be a *native* oxide, any artificial oxide being equally effective; that kind which can be had cheapest is therefore generally preferred. The operation may be thus explained:—

The cast-iron, of which this cutlery is made, is brittle in the first instance, like other cast-iron, in consequence of the carbon contained in it; but the great heat which it undergoes, aided by the pulverized oxide, separates the carbon: this uniting with the oxygen of the ground oxide of iron, is dissipated in the state either of carbonic oxide or carbonic acid gas, and the goods are then converted into a state very similar to that of good cast-steel cutlery.

To prevent misconception, it may be necessary to state, that cast-iron which contains a *large* proportion of carbon is less brittle than that which is combined with a smaller quantity. It can also be filed and cut with a cold chisel, while the latter, although it may be more readily broken, effectually resists the action both of the chisel and the file. In conformity with these facts, small machinery made of common cast-iron may be softened merely by cementation with a carbonaceous substance, thereby

augmenting its dose of carbon, and rendering it capable of being smoothed by the file.

I understand that the best pig-iron is always chosen for making the various articles of cutlery, while the poorest iron ore, if free from sulphur, may be pulverized and stratified with them to afford oxygen.

After several years experience, Mr. Thomas Lucas has been enabled to bring this process to such a state of perfection, that his cast cutlery will bear a polish[95] equally brilliant with the best cast-steel goods, as I can testify from my own observation; and will also take as fine an edge, so that some of the best judges of cutlery cannot distinguish the difference. When, however, the cast cutlery wares which have been thus annealed, are submitted to the usual processes of hardening and tempering, they are apt to be more brittle than those edge tools which are made in the usual way with the best steel.

It has also been found that by varying the process small pig-iron castings can be converted into good malleable iron: in consequence of this the Patentee now makes a great variety of small iron utensils by *casting*, which were formerly made only

[95] Directions by Messrs. Stodart and Hume for preserving polished steel instruments from rust by means of an ethereal solution of gold, are given in Nicholson's *Journal*, vol. xi. p. 215. A paper by Mr. Stodart on covering steel with platinum is printed in the same volume, page 282. See also a paper on the same subject by Guyton Morveau in the *Annales de Chimie*, tome 77, page 297.

on the anvil of the blacksmith; and when he has converted the metal to the quality of soft malleable iron, these articles are found to be equally fit for a great variety of purposes, and can be afforded at a much lower rate than similar goods which have been modelled by hand, as heretofore. He has become so complete a master of this business, that he can convert cast-iron goods either into the state of wrought iron or steel at pleasure.

Mr. Lucas has shown me articles made with pig-iron which appeared perfectly malleable. I have seen cast nails which would bend like common wrought iron nails, and small articles that would bear even to be welded together by the usual process.

In conducting these operations, he has sometimes observed that when dark or highly carburetted cast-iron is fused in small quantities, plumbago is separated, and the metal, by thus losing a part of its carbon, becomes white. Here a question occurs; —Why did not the plumbago separate on the first cooling? Is it not probable that crude iron combined with a certain portion of carbon, is thereby rendered capable of dissolving and retaining in combination a quantity of plumbago, in the same manner as water saturated with carbonic acid, will dissolve an extra portion of carbonate of lime?

I have also to observe, that the steel which the Patentee makes by the process of cementation, possesses, in common with that manufactured in the usual way, the susceptibility of being powerfully

magnetized, and appears to retain the magnetic property as well as other steel. He has indeed in his possession a small instrument in the form of a horse-shoe magnet, made with *cast-iron* and afterwards converted by his peculiar process to steel, which he has had magnetized, and it is now capable of sustaining, by its magnetic power, a weight nearly equal to three pounds.

I have only to add that Mr. Lucas has very obligingly furnished me with a drawing of the furnace which he employs in these processes, and, with his permission, I have thought it worth while to have a copper-plate engraving of it made to accompany this Essay.

Since the publication of the former edition of these Essays, Messrs. Stodart and Faraday have undertaken a series of very important experiments on the alloys of iron and steel, with various other metals; the object of which was, first to ascertain whether any alloy could be artificially formed, better for the purpose of making cutting instruments than steel in its purest state; and, secondly, whether any such alloys would, under similar circumstances, prove less susceptible of oxidation. An account of these experiments having been given in considerable detail, both in the Philosophical Transactions, and in the Quarterly Journal of Science, I trust that a careful abridgement of all the papers on this subject, or at least a transcript of the most

important results of the several experiments, will be useful and highly acceptable to the public.

These Experimentalists found that by combining a very small portion of alumina with good steel, an artificial *wootz* was produced, which, when the surface was polished, gave, on the application of dilute sulphuric acid, the beautiful damask appearance which has hitherto peculiarly belonged to the Asiatic steel. It is remarkable that the wootz, although repeatedly fused, retains the peculiar property of presenting a damasked surface, when forged, polished, and acted upon by dilute acid [96].

"Platinum, rhodium, gold, silver, nickel, copper and tin were alloyed with both English and Indian steel, and in various proportions. All these metals have an affinity for steel sufficiently strong to make them combine; and this is so remarkable with platinum, that it will fuse when in contact with steel, at a heat at which the steel itself is not affected [97].

"When one part of silver to 500 parts of steel were properly fused, a very perfect button was produced. The specimen forged remarkably well, although very hard. By a delicate test every part of the bar gave silver. This alloy, they say, is decidedly superior to the very best steel, and this excellence is unquestionably owing to combination with a minute portion of silver. It has been repeatedly made, and always with equal success. Various

[96] The *Quarterly Journal of Science*, vol. ix. page 320.
[97] *Ibid.* page 325.

cutting tools have been made from it of the best quality. This alloy is perhaps only inferior to that of steel with rhodium, and it may be procured at a small expense; the value of the silver where the proportion is so small, is not worth naming; it will probably be applied to many important purposes in the arts [98].

"The alloys of steel with platinum, when both are in a state of fusion, are very perfect, in every proportion that has been tried. Equal parts by weight form a beautiful alloy, which takes a fine polish, and does not tarnish; the colour is the finest imaginable for a mirror. The specific gravity of this beautiful compound is 9·862.

"The proportions of platinum that appear to improve steel for edge instruments are from 1 to 3 per cent.; 1·5 per cent. will probably be very nearly right [99].

"The alloys of steel with rhodium are likely to prove highly valuable. The scarcity of that metal must, however, operate against its introduction to any great extent. This alloy was made at the suggestion of Dr. Wollaston. The proportions of rhodium used, were from 1 to 2 per cent. The valuable properties of the rhodium alloys are hardness, with sufficient tenacity to prevent cracking either in forging or in hardening. This superior hardness is so remarkable, that in tempering a few cutting

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[98] *Quarterly Journal of Science*, vol. ix. page 326.
[99] *Ibid.* page 328.

articles made from the alloy, they required to be heated full 30° of Fahrenheit higher than the best wootz, wootz itself requiring to be heated full 40° above the best English cast-steel. Thermometrical degrees are named, that being the only accurate method of tempering steel [100]."

"Gold forms a good alloy with steel. Experience does not yet enable us, say they, to speak of its properties. It certainly does not promise to be of the same value as the alloys of silver, platinum and rhodium [101]."

The authors conclude this valuable paper by observing that, "from the facility of obtaining silver, it is probable that its alloy with steel is the most valuable of those we have made. To enumerate its applications would be to name almost every edge tool. It is also probable that it will prove valuable for making dies, especially when combined with the best Indian steel [102]."

In a subsequent paper [103] these Experimentalists give an account of the manufacture of the alloys upon a larger scale. In these experiments they discovered, with regard to the silver alloy, that "steel will only retain one 500dth part in union; when more was used, it either evaporated, or separated as the button cooled, or was forced out in forging. The alloy was excellent, and the trifling addition

[100] *Quarterly Journal of Science*, vol. ix. page 329.
[101] *Ibid.* page 329.
[102] *Ibid.* page 329.
[103] *Philosophical Transactions* for the year 1822, part ii. pages 253—270.

of price furnishes no obstacle to its general employment."

"Steel alloyed with the 100dth part of platinum, though not so hard as the silver alloy, has more toughness; hence its value, where tenacity as well as hardness is required: the extra cost is more than repaid by its excellence.

"The action of acids on these alloys is curious, and especially in respect to that of platinum, which is acted upon by diluted sulphuric acid with infinitely greater rapidity than the unalloyed steel; indeed, an acid that scarcely touches the pure steel, dissolves the alloy with energetic effervescence. This is probably referable to electrical excitation."

It is remarkable that when pure iron is substituted for steel, the alloys so formed are much less subject to oxidation. Three per cent. of iridium and osmium, fused with some pure iron, gave a button, which, when forged and polished, was exposed, with many other pieces of iron, steel and alloys, to a moist atmosphere; it was the last of all showing any rust. The colour of this compound was a distinct blue[104].

Dr. Brewster states that Mr. Stodart favoured him with specimens of several of these alloys for optical purposes; and though various plates of polished steel kept beside them for more than a year, were all affected with rust, yet not one of the alloys had suffered the least change[105].

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[104] *Quarterly Journal of Science*, vol. xiv. page 378.

[105] The *Edinburgh Philosophical Journal*, vol. vii. page 350.

So important were these discoveries of Messrs. Stodart and Faraday considered in France, that "The Society for the Encouragement of National Industry" directed a Special Commission to repeat their experiments and report on the value of the several alloys which they had described. This Report was printed in the year 1821 and is highly flattering to our English Chemists[106]. A second Report was made to the same society in the name of the Committe of Mechanical Arts, on the Steel Damasked Blades of M. Degrand-Gurgey of Marseilles, in which the Committee speak of "la précieuse découverte de MM. Stodart et Faraday," and promise at some future time to repeat all the experiments which led to those discoveries; especially those whereby our countrymen were enabled to give to steel that property of damasking which formerly belonged exclusively to the Indian wootz[107].

When the public had been informed of the success which had attended the experiments of Messrs. Stodart and Faraday, M. Berthier was induced to try the effect to be obtained by adding a portion of chromium to steel. "Two alloys of cast-steel and chromium were made, one with 0.01, the other

[106] *Rapport fait à la Société d'Encouragement pour l'Industrie Nationale, au Nom d'une Commission Spéciale, sur les Aciers Damassés de M. Sir, Henry, &c.* Par M. Héricart de Thury. A Paris, Quarto 1821.

[107] *Second Rapport fait à la Société d'Encouragement pour l'Industrie Nationale, au Nom du Comité des Arts Méchaniques, sur les Lames Damassées de M. Degrand-Gurgey de Marseille.* Par M. Le Vicomte Hericart de Thury. Quarto, Paris 1821.

with 0.015 of chromium. These, he says, both forged well, the first better than cast-steel. A knife and a razor were made from them, and both proved very good; their edges were hard and solid, but their most remarkable character was the fine damask they took, when washed over with sulphuric acid. This damask was composed of white silvery veins, and nearly resembled that given by the alloy of steel and silver. The white parts are probably pure chromium, on which acids have no action. This chromic steel was prepared by fusing together cast-steel and the alloy of chromium and iron [108]."

[108] *Quarterly Journal of Science*, vol. xii. page 174. *Annales de Chimie et de Physique*, tome xvii. page 55.

ESSAY XVI.

ON

THE MANUFACTURE

OF

TIN-PLATE.

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AS the processes in this manufacture are more numerous and complicated than is generally imagined, it may be advisable to preface the account with an enumeration of some of those properties of tin which will be most likely to explain the rationale of the principal operations.

Tin has a great affinity for several of the other metals—particularly for zinc, mercury, copper, antimony, lead and iron; and owing to these affinities, its employment in the arts is very considerable.

Tin, with zinc, forms a metal of close grain, very useful for many purposes, especially for the formation of *pewter*. The zinc is found to impart great hardness to the tin, without lessening its ductility.

The combination of mercury and tin, in which the tin is dissolved by the mercury into a very soft amalgam, is largely employed, as is well known, in silvering the backs of mirrors, and for other purposes in the arts. An amalgam of tin of greater consistence was formerly in use in the museums of Paris for closing the mouths of glass-bottles containing sundry curious and valuable preparations.

Copper is also alloyed with tin for various purposes of manufacture. This metallic mixture is employed in making what are called bronze statues; for casting bells, and pieces of artillery, and also for the fabrication of medals and medallions. In some of these cases the tin is mixed with copper, on account of its property of rendering the copper more fusible; and this was probably the reason why the ancient Romans used that metal in the greater part of their brass coinage. It is owing to the affinity of tin for copper, that vessels of capacity, made with the latter metal, for culinary and other purposes, are so readily covered with a coating of tin, to preserve them from the action of substances which would not fail to erode copper, if unprotected by some such covering. The affinity of tin for copper is further exemplified by the process of whitening *pins*, which is effected by boiling

the pins with granulated tin in a lie made with alum and tartar[1].

An useful alloy is likewise formed by the mixture of tin and antimony. This metallic compound is very white, extremely hard, and will bear a very fine polish. On these accounts it is employed in making specula for telescopes, and also for the manufacture of rolled plates to engrave music upon.

The next metal which I have mentioned as uniting readily with tin, is lead. This metal will combine with tin in any proportion; and in most proportions the lead acquires a greater degree of fusibility by its union with the tin. It is this alloy which forms plumbers' solder; but that compound is prepared with different proportions of tin, according to the purpose for which it is intended. The article called tin-foil, used for lining tea-caddies, for coating electrical jars, and for other purposes, is also made from a mixture of these two metals.

But what is more relevant to the subject of this paper, is the chemical affinity which subsists between *tin* and *iron*. One of the strongest proofs of this affinity is derived from the circumstance that even *cast*-iron may be tinned in the same manner as wrought-iron. Of late years, cast-iron saucepans, and pots of a large size, are permanently tinned on their inner surfaces, to prevent the liquors which are boiled in them from acquiring any stain by a partial dissolution of the iron. Many other

[1] An interesting Memoir (by M. Gadolin) on the Tinning of common Pins, will be found in the *Journal de Physique*, 1789.

articles, such as bridle-bits, common stirrups, small nails, &c. are now made much cheaper than formerly, by first fabricating them in cast-iron, and then covering them with a thin coat of tin, by the immersion of them in a hot mass of that metal in a state of fluidity.

That these effects are owing to chemical affinity, cannot be doubted, when it is considered, that in all these cases the pores of the iron are in some degree actually penetrated by the tin.

In the manufacture of *tin-plate*, which I am now about to describe, a similar effect is produced, and also by the same means. Plates of iron properly prepared, are immersed in a large mass of melted tin, which is kept hot by a fire constantly burning underneath it;—the consequence of which is, that the tin in some measure penetrates the iron, and this attaches other tin to it, so that the whole surface of the iron acquires, by this means, a complete covering of that metal.

As no accurate account has ever yet been given of the various processes by which this is effected, the following outline may probably be acceptable to the public.

English bar-iron of the finest quality, called tin-iron, and which is generally prepared with *charcoal* instead of mineral coke, and made with the greatest care, for this particular purpose, is first cut to the necessary length, and then rolled at the mill, by a process which is peculiar to this manufacture,

into plates of the requisite thinness, and of such form as is suitable for the business. These plates are then cut by hand-shears to the sizes suitable for the different markets[2]. And as the shearer shears the plates, he piles them in heaps, occasionally putting one plate the cross way, to keep each box separate. Two hundred and twenty-five plates are called a box; but they are not put into boxes of wood in this stage of the operation. The iron plates now go into the hands of the *scaler*, who takes them from the shear-house, and bends each of them singly across the middle, into this form Λ, preparatory to their being cleaned for tinning, and for the conveniency of putting them into the scaling furnace, as will be more fully explained hereafter.

This furnace, or oven, is heated by *flame* thrown into it from a fire-place of a peculiar construction; and it is this flame that scales the plates, which are put into the oven in rows, and arranged three in each row, until the oven is full. It will be obvious that if they lay flat on the floor of the oven, the flame could play only on one side of each plate, whereas, by being bent in the form already described, the flame can operate equally on both sides. It may here be remarked that the form of all tin-plates, one sort excepted, is that of a parallelogram, and that if a piece of stiff paper, or pasteboard,

[2] These plates are generally cut *by hand*; but an ingenious whitesmith in Glamorganshire a few years ago invented a method of shearing them by *a machine*. This machine is worked by a water-wheel, and will shear 100 boxes per day; whereas a hand-shearer cannot complete more than 25 boxes in the same period of time.

13¼ inches long, and 10 inches wide, be bent in the centre at an angle of about sixty degrees, and then put to stand on the two ends, we shall have the form of a plate No. 1. properly bent for the scaling oven.

The operation of *cleansing*, as it is called, and which is preparatory to the process of scaling, is commenced by steeping the plates for the space of four or five minutes, in a mixture of muriatic acid and water, in the proportion of four pounds of acid to three gallons of water. This quantity of the diluted acid will generally be sufficient for eighteen hundred plates, or eight boxes of 225 plates each.

When the plates have been steeped for the time prescribed, they are taken out of the liquor, and placed upon the floor, three in a row, and then by means of an iron rod put under them, they are conveyed to a furnace heated red-hot, where they remain until the heat takes off the scale, the removal of which was the object in submitting them to that high temperature.

When this is effected, the plates are taken to a floor, where they are suffered to cool; they are then straightened, and beaten smooth upon a cast-iron block. The workman knows by the appearance of the plates during this operation, whether they have been well scaled; for if they have, that is, if the rust or oxide which was attached to the iron has been properly removed, they will appear mottled with blue and white, something like marbled paper. The operation that we have now been describing is called *scaling*.

As it is impossible the plates can go through this process without being in some measure warped, or otherwise disfigured; they are now rolled a *second* time, between a pair of cast-iron rollers, properly hardened and finely polished. This operation makes both sides of the plates perfectly smooth, and imparts a sort of polish to their surfaces. These rollers are each about 17 inches long, and 12 or 13 inches in diameter; but I am inclined to think that if the diameter was greater[3], they would set the plates flatter, and do the work better in every respect.

The technical name of this apparatus is *rolls*, not *rollers*. All the rolls which are employed in rolling plates, either hot or cold, in this manufactory, are *hard* rolls; and there is as much difference between a pair of *hard* cast-iron rolls, and a pair of *soft rolls*, although they may both be run out of the same pot of metal, as there is between iron and steel. The workmen inform me that the difference is entirely occasioned by the manner of casting them—the soft rolls being cast in sand, whereas the hard rolls are formed by pouring the metal into a thick cast-iron box—and that the metal, by coming in contact with the cold box is sufficiently chilled to render the whole face of the roll entirely hard. The difference in the temper of these two kinds of

[3] Since the above was written, I have submitted the manuscript to a gentleman who is very largely engaged in the manufacture of tin-plates, and he tells me that the cold rolls which are employed in his work, are 30 inches in diameter.

rolls is so great, that when they are put into the lathe to be turned perfectly true, the turnings from the one will be $\frac{1}{8}$th of an inch in thickness, whilst the turnings which come from the other are not larger than very fine needles. The temper of cast-iron thus varying according to the nature of the mould into which it is poured, is a circumstance that appears to me to be deserving of attention in the manufacture of a variety of other utensils employed in the arts[4].

These rollers are used without heat; but they are screwed down very close one upon the other, only leaving bare room for the plates to pass, that the utmost attainable degree of pressure may be given to them. This last operation is called COLD ROLLING.

When the plates have undergone this process, they are put one by one into troughs filled with a liquid preparation called *the lies*.

This is merely water in which bran has been steeped for nine or ten days until it has acquired a sufficient acidity for the purpose. The design of putting the plates into the troughs *singly*, is, that there may be more certainty of the liquor getting

[4] The art of making good hard rolls appears to be very imperfectly understood, because the difficulty of producing them is very great. Not one in three can be called thoroughly good. For, if they are not sufficiently hardened on the surface, they will not wear; whereas, if they are made hard throughout, or *struck hard to the centre*, as the workmen call it, they will generally crack across the middle and become useless. This fault is quite independent of air bubbles or flaws, which are always discoverable in turning by the lathe.

between them, and both the sides of every plate being soaked alike in the lies. In this liquor they remain for ten or twelve hours standing on the edges; but they are turned, or inverted, once during that time. This operation is called *working* in the lies.

The next operation is that of steeping in a mixture of sulphuric acid and water, in proportions which vary according to the judgement of the workmen.

The trough in which this operation is conducted, is made with thick lead, and the interior is divided by partitions of lead. Each of these divisions is by the workmen called *a hole*, and each of them will contain about one box of plates. In the diluted sulphuric acid which is in the different compartments of this vessel, the plates are agitated for about an hour, or until they have become perfectly bright, and entirely free from the black spots which are always upon them when they are first immersed in it.

Some nicety however is required in this operation; for, if they remain too long in the acid, they will become stained, or blistered by it, as the workmen term it; but practice enables a careful operator to judge of the time when they ought to be removed. This, however, is one of the most difficult parts of the business, as few men like to work in it; though I understand that a good pickler is highly valued by his employers, and obtains great wages. It is necessary to notify that this, and the former process with the acidulated water, are both

hastened by giving to those menstrua an increase of temperature; and this is effected by means of heated flues which run under each trough. Little additional heat is necessary in summer, however, as 90° or 100° of Fahrenheit is a temperature sufficiently high for either of these operations.

When the plates come out of the pickle, they are put into pure water, and scoured in it with hemp and sand, to remove any remaining oxide, or rust of iron that may be still attached to them; for, wherever there is a particle of rust or even *dust* upon them, there the tin will not fix; and they are then put into fresh water to be there preserved for the process of tinning. The design of putting the plates into pure water, after they come out of the sours, is to prevent their becoming again oxidized; for it has been found that after these operations they will acquire no rust, although they should be kept twelve months immersed in water.

It will be perceived that all these processes are nothing more than preparatory measures for the operation which is to succeed, viz. that of TINNING.

For this purpose an iron pot is nearly filled with a mixture of *block* and *grain* tin, in a melted state; and a quantity of tallow or grease, sufficient, when melted, to cover the fluid metal to the thickness of four inches, is put to it. However, as some persons may not be acquainted with the difference between *block* and *grain* tin, it may be remarked, before we proceed, that the metal known in commerce by the name of block tin, is prepared either

from the mineral called *tin-stone*, or the one known in Cornwall by the name of *tin-pyrites*, whilst the article called *grain tin* is smelted from an ore which is found in grains, called *stream tin* ore, under beds of alluvial soil, in low situations, whither in the course of ages it has been washed from the hills by a succession of torrents of rain. The former, which is produced in the greatest abundance, is always contaminated with a portion of iron, sulphur, and other injurious substances, and is therefore only employed for common purposes; while the grain tin, which is nearly free from every impurity, and usually from twenty to thirty shillings per hundred weight dearer, is used in many processes of dyeing, and in all other cases where *pure* tin is required. I am also desirous of remarking, that in my opinion it would be more profitable to the proprietor of a tin-plate work, if he were to use *grain* tin alone, or grain tin mixed with that kind which is known by the name of "Refined Tin," because these kinds not only contain less dross, but they melt, as I know by my own experience, into a more fluid metal; and consequently, more would run off the plates in the operation of tinning, and less tin would be consumed. At present these manufacturers use the block and grain tin, in equal proportions.

When the tin-pot has been charged in the way above mentioned, the metal is heated from a fireplace underneath it, and by flues which go round

the pot, until it is as hot as it can be made without actually inflaming the grease which swims upon its surface. The use of the grease is to preserve the tin from the action of the atmosphere, and consequently to prevent it from oxidizing. By melting a little tin or lead in an iron ladle, and, when the dross is skimmed off, putting a morsel of tallow upon the metallic fluid, the effect of the tallow in cleansing the face of the metal will be evident. The workmen also say, that it increases the affinity of the iron for the tin, or, as they express it, that it makes the iron plates take the tin better.

It is curious that *burnt grease*, or any kind of empyreumatic fat, effects this purpose better than pure fresh tallow.

Another pot, which is fixed by the side of the tin-pot, is filled with grease only; and in this the prepared plates are immersed, one by one, before they are treated with the tin; and when the pot is filled with them, they are suffered to remain in it so long as the superintendant thinks necessary. If they remain in the grease an hour, they are found to tin better than when a shorter time is allowed them.

From this pot they are removed, with the grease still adhering to them, into the pot just before spoken of, which contains the body of melted tin; and in this they are placed in a vertical position. Three hundred and thirty-eight or three hundred and forty plates are usually put into this pot at

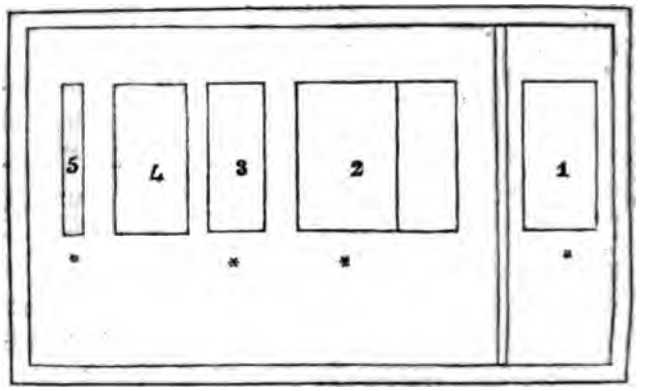
once[a]; and for the sake of their being thoroughly tinned, they usually remain in it one hour and a half; but occasionally more time is required to complete this operation.

When the plates have lain a sufficient time immersed in the melted tin, they are taken out and placed upon an iron grating, that the superfluous metal may drain from them; but, notwithstanding this precaution, when they become cold there is always more metal found adhering to them than is necessary; and this is taken off by a subsequent process called *washing*. As this process is rather complicated, it will be necessary to describe it with some minuteness.

In the first place, the wash-man prepares an iron pot which he nearly fills with the best grain tin in a melted state—another pot of clean melted tallow, or lard free from salt—a third pot with nothing within it but a grating to receive the plates—and a fourth, called the *listing-pot*, with a little melted tin in it, about enough to cover the bottom to the depth of a quarter of an inch. The whole will however be better understood by referring to the following drawing, which exhibits the several vessels

[a] It is immaterial how many plates are put into the tin-pot at once—but this number is usually fixed upon, because it amounts to about one box and a half of plates: though, as they are put in edgewise, it is necessary the pot should be nearly filled, to prevent their falling down—in which case they could not be got out, through so heavy a body of metal, without much difficulty.

in the order in which they stand in the manufactory, all supported by substantial brick-work.



The building in which the pots are fixed is called the *Stow*. The plates are worked from the right to the left of the stow, as will be evident by attending to the uses of the separate pots.

No. 1. represents the tin-pot.

2. The wash-pot with the parting within it.

3. The grease-pot.

4. The pan, containing a grating at the bottom[6].

5. The list-pot.

The drawing represents the *surface* of the pots. The asterisks show the places where the workmen stand, and also mark those pots which have heated flues under them. No. 4 has no fire under it.

[6] This pan is designed for the reception of the plates as the boy takes them out of the grease-pot. It has no fire underneath it.

The parting in the wash-pot No. 2 is a late improvement. The design of it is to keep the dross of the tin from lodging in that part of the vessel where the last dip is given to the plates. By using the *common* tin in the first process of tinning, much oxide, or dross, adheres to the surface of the plates, and this runs off in the wash-pot, and comes to the face of the new metal; but this parting enables the operator to prevent it from spreading over the whole surface of the pot. Were it not for this parting, the wash-man must skim the oxide off the fluid metal every time he puts plates into it.

The pots of which I have given a sketch being all in a state of fitness, the wash-man commences his part of what remains of the business, by putting the plates which have undergone the various operations hitherto described into the vessel of grain-tin, called the wash-pot[7]. The heat of this large body of melted metal soon melts all the loose tin on the surface of these plates, and so deteriorates the quality of the whole mass, that it is usual, when sixty or seventy boxes have been washed in the grain tin, to take out the quantity of a block, say three hundred weight, and replenish the wash-pot with a fresh block of pure *grain*-tin. These vessels generally hold three blocks each, or about half

[7] None but *grain*-tin is ever put into this vessel; for the whole of the common tin which is consumed in such manufactories, is used in the *first* process, viz., that which is called *tinning*.

a ton weight of metal. That which is taken out of the wash-pot when it is replenished with pure metal, is given to the tin-man to put into his pot.

When the plates are taken out of the wash-pot, they are carefully brushed on each side with a brush of hemp of a peculiar kind, and made expressly for the purpose. As this part of the business requires considerable adroitness and expedition, it may be worth while to explain it a little more in detail.

The wash-man first takes a few plates out of the wash-pot, and lays them together before him on the stow; he then takes one plate up with a pair of tongs, which he holds in his left hand, and with a brush held in his right hand brushes one side of the plate; he then turns it, and brushes the other side, and immediately dips it once more into the hot fluid metal in the wash-pot, and without letting it out of the tongs instantly withdraws it again, and plunges it into the grease-pot (marked No. 3) adjoining to the wash-pot from whence he had just taken it.

A person who has not seen the operation, can form but a very inadequate idea of the adroitness with which this is performed: practice, however, gives the workman so much expedition, that he is enabled to make good wages, although he obtains only three-pence for the brushing and metallic-washing of 225 plates. I am informed that an expert wash-man, if he makes the best of his time, will wash 25 boxes, consisting of 5625 plates, in

twelve hours; notwithstanding every plate must be brushed on both sides, and dipped twice into the pot of melted tin.

Why the plates should be dipped *twice* during this part of their manufacture, may perhaps require some explanation. It must be recollected that they are brushed quite hot, and before the tin is set; therefore, if they had not the last dip, the marks of the brush would be visible. Moreover, the brush takes the greatest part of the tin off them, so that if they were removed to the grease-pot without being re-dipped, the hot grease would take off what remained.

The only use of the grease-pot is to take off any superfluous metal that may be upon the plates: but this is an operation that requires great attention, because, as the plate is immersed in the grease while the tin is in a melting, or at least in a soft, state upon it, a part *must run* off, and the remainder become less and less while the plate continues in it; therefore, if these plates should ever be left in the melted tallow longer than is absolutely necessary, they will doubtless require to be dipped a third time in the tin. On the other hand, if the plates were to be finished without passing through the grease, they would retain too much of the tin, which would be a loss to the manufacturer; and besides, the whole of the tin would appear to be *in waves* upon the iron.

It is also equally necessary to attend to the temperature of the melted tallow, which must be colder

or hotter in proportion as the plates are thicker or thinner; for if, when the tallow is of a proper temperature for a thin plate, a thick one was to be put into it, it would come out, not of the colour of tin as it ought to be, but as yellow as gold. The reason of this is evident. The thick plate contains more heat than a thin one, and consequently requires the tallow to be at a lower temperature. On the contrary, if a parcel of *thin* plates were to be worked in a pot of tallow which had been prepared for *thick* plates, such a pot would not be hot enough to effect the intended purpose.

It is a common observation that in most of our manufactures, and in all chemical speculations, theory and practice are generally at variance: but there are few manufactures, perhaps, where there are so many minutiæ which would escape the notice of a casual observer, and yet that require to be carefully attended to, in order to produce a good result, as in that which we have now been describing; and should the perusal of this paper occasion but one individual to pause, who was about to enter into a new concern with which he was only partially acquainted, I shall have written to a good purpose.

But to return to the process. When the plates are sufficiently brushed, they are again immersed one by one in the pot of melted tin, as has already been remarked, and immediately from this they are put into the pot of tallow above mentioned. This pot has pins fixed within it, in such a manner as to prevent the plates from touching each other;

and this part of the process is conducted in the following manner:

When the wash-man has passed *five* of the plates through the melted tin, and from thence into the pot of tallow above mentioned, a boy takes out one of them and puts it into the empty pot to cool, and the wash-man puts in the *sixth* plate. The boy then takes out a *second* plate, and lays it to cool likewise; when the man puts in his *seventh*, and so they go on, in this regular manner, until the whole of the parcel is finished.

In consequence of the plates being immersed in the melted tin in a vertical position, there is always, when they have become cold, a wire of tin on the lower edge of every plate which is necessary to be removed, and this is done by a boy, called the list-boy, who takes the plates when they are cool enough to handle, and puts the lower edge of each, one by one, into the list-pot, which is the vessel that was before described, as containing a very small quantity of melted tin, and the same as that which I have marked No. 5. When the wire of tin is melted by this last immersion, the boy takes out the plate, and gives it a smart blow with a thin stick, which disengages the wire of superfluous metal, and this falling off, leaves only a faint stripe in the place where it was attached. This mark may be discovered on every tin-plate which is exposed for sale; the workmen, in the manufacture of them, call it the *list*.

Nothing now remains but to cleanse the plates

from the tallow. This is done by means of bran, and as they are cleansed they are put into strong wooden boxes, or boxes of *sheet-iron*, made exactly to fit them; and this completes the whole business. Each box contains a determinate number of plates; and the following table will show the different sizes of tin plate which are made in Great Britain, and the marks by which each kind is known in commerce.

Names	Sizes	No. in a Box	Weight of each Box			Marks put on the Boxes
	Inch					
Common, ... No. 1.	13¾ by 10	225	1	0	0	CI
Do ..... 2.	13¼ by 9¾			3	21	CII
Do ..... 3.	12¾ by 9¼			3	16	CIII
Cross ..... No. 1.	13¾ by 10		1	1	0	XI
Two Cross ..... 1.			1	1	21	XXI
Three Cross ..... 1.			1	2	14	XXXI
Four Cross ..... 1.			1	3	7	XXXXI
Common Doubles ..	16¾ by 12½	100		3	21	CD
Cross Doubles			1	0	14	XD
Two Cross do.			1	1	7	XXD
Three Cross do.			1	2	0	XXXD
Four Cross do.			1	2	21	XXXXD
Com. small Doubles. .	15 by 11	200	1	2	0	CSD
Cross do. .... do...			1	2	21	XSD
Two Cross, ... do...			1	3	14	XXSD
Three do. .... do...			2	0	7	XXXSD
Four do. .... do...			2	1	0	XXXXSD
Wasters Com. No. 1.	13¾ by 10	225	1	0	0	WCI
Do. Cross .... 1.	13¾ by 10		1	1	0	WXI

A List of the Current Wholesale Prices of Tin-Plate in London.

Sorts	Weights	No. in each Box	Prices per Box in Sept. 1817	Prices per Box in 1828
	lb. lb.		s.	s. d.
C No. 1.	112 to 115	225	41	47
C 2.	103 .. 106		39	45
C 3.	98 .. 101		37	43
X No. 1.	140 .. 142		49	53
XX 1.	160 .. 163		55	58
XXX 1.	182 .. 185		61	63
CD	98 .. 103	100	37	64–6 } 150 sheets each.
XD	126 .. 129		45	73–6
XXD.....	147 .. 150		51	81
XXXD	168 .. 171		57	88–6
CSD.....	167 .. 170	200	63	69
XSD.....	188 .. 191		69	75
XXSD	209 .. 212		75	80
Western CI ..	112 .. 115	225	35	44
Do. XI	140 .. 143		43	50

Having given so detailed an account of the manufacture of tin-plate, it may be expected that I should say a few words on the *origin* of the art.

Formerly none of the English workers in iron or tin had any knowledge whatever of the methods by which this useful article could be produced; our ancestors, from time immemorial, having supplied themselves with it from Bohemia and Saxony. The establishment of this manufacture in those districts, was doubtless owing to their vicinity to the tin mines in the circle of Ersgebirg, which, next to those of Cornwall, are the largest in Europe. The ore which is found there is not the *tin-pyrites*, but

the mineral called *tin-stone*; and it is curious that it should occur in abundance, both on the Bohemian and Saxon sides of the mountain group: accordingly, manufactories of tinned iron have been established in both those kingdoms. Alluvial deposits of grain-tin are also found in the same vicinity.

From the time of the invention of tin-plate to the end of the seventeenth century, not only England but also the whole of Europe depended upon the manufactures of Bohemia and Saxony for their supply. However, about the year 1665 Mr. Andrew Yarranton, encouraged by some persons of property, undertook to go over to Saxony to acquire a knowledge of the art; and on his return, several parcels of tin-plate were made of a superior quality to those which we had been accustomed to import from Saxony; but owing to some unfortunate and unforeseen circumstances, which are all detailed by Mr. Yarranton in his very valuable publication[s], the manufactory was not at that time established in any part of Great Britain.

As it is now difficult to procure a copy of the work from which I have obtained a knowledge of the manner in which this manufactory was brought into England, an abridgement of the author's own account of the transaction will probably be interesting to the public.

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[s] *England's Improvement by Sea and Land,* with many plates of Plans, Charts, &c. in two parts, by Andrew Yarranton, Gent. Part I. Quarto. London, 1677. Part II. London, 1681.

"Knowing," says Mr. Yarranton, "the useful-
"ness of tin-plates, and the goodness of our metals
"for that purpose, I did (about sixteen years since[9])
"endeavour to find out the way for making there-
"of; whereupon, I acquainted a person of much
"riches, and one that was very understanding in
"the iron manufacture; who was pleased to say,
"that he had often designed to get the trade into
"England, but never could find out the way. Upon
"which it was agreed, that a sum of monies should
"be advanced, by several persons, for the defraying
"my charge of travelling to the place where these
"plates were made; and from thence to bring
"away the art of making them. Upon which, an
"able fire-man, that well understood the whole
"nature of iron, was made choice of to accompany
"me; and being fitted with an ingenious inter-
"preter, that well understood the language, and
"that had dealt much in that commodity, we
"marched first for Hamburg, then to *Lipswick*;
"and from thence to *Draisden*, the duke of *Sax-*
"*onies* Court, where we had notice of the place
"where the plates were made; which was in a large
"tract of mountainous land, running from a place
"called *Seger-Hutton*, unto a town called *Awe*,
"being in length about twenty miles; the tin-works
"being there fixed upon a great river running clear

[9] This account is dated February 2nd, 1681; I therefore conclude that Mr. Yarranton's journey to Saxony must have been about the year 1665.

"along the valley, and also upon some little rivulets "that run out of the mountains of Bohemia and "Saxony; and coming to the works, we were very "civilly treated, and, contrary to our expectation, "we had much liberty to view, and see the works "go—with the way and manner of their working "and extending the plates, as also the perfect view "of such materials as they used in clearing the "plates, to make them fit to take tin, with the way "they use in tinning them over, when cleared from "their rust and blackness. And having (as we "judged) sufficiently obtained the whole art of "making and tinning the plates, we then came for "England, where the several persons concerned in "the affair thought fit to make some trial in making "some small quantities of plates and tinning them, "which was done; and all workmen that wrought "upon them agreeing that the plates were much "better than those which were made in Germany; "upon which, preparation was making to set this "beneficial thing at work;—but, it being under- "stood at London, A PATENT was trumpt up, and "the patentee was countenanced by some persons "of quality—and what, with the patent being in "our way, and the richest of our partners being "afraid to offend great men in power, who had "their eye upon us, it caused the thing to cool, "and the making thereof was neither proceeded in "by us, nor possibly could be by him that had the "patent; because neither he that hath the patent,

"nor those that have countenanced him, can make "one plate fit for use[10]."

This enterprising individual, who spent the greater part of his life in promoting schemes for the good of his country, and who, in the opinion of Bishop Watson, ought to have had a statue erected to his memory, proceeds to inform us, that before they were stopped by the patent they had made "many "thousand plates from iron raised in the forest of "Dean, and tinned them over with Cornish tin, "and the plates proved far better than the German "plates, by reason of the toughness and flexible-"ness of our forest iron. One Mr. Dison, says he, "a tinman in Worcester, one Mr. *Lydiate* near "Fleet-bridge, and one Mr. *Harrison* near the "Kingsbench, have wrought many, and they know "their goodness[11]."

In another place this interesting writer informs us, that "when he was in Saxony the different es-"tablishments for making tin-plates were very nu-"merous, and that most of them belonged to the "duke[12]." "The trade," says he, "is so great, "that, by computation, no less than 80,000 men "depend upon it; and when the plates are finished, "they are sent by land to *Lipsick*, from thence to the "*Elbe* river, and so down to *Hamburg*, and from "thence sent by sea as far as trade is known[13]." "There was," says he, "no tin any where in Eu-"rope, except in Cornwall, until a Cornish man

[10] *England's Improvement, &c.* page 149—152, Part II.
[11] Page 173. [12] Page 155. [13] Page 172.

" found tin in the mountains of Saxony, near a town " called *Awe*, where *his statue is yet to be seen.* " The tin works are fixed upon a great river running " down the valley; and the tin, iron and woods, " grow in and upon the mountains adjoining to " both sides the river; and those tin-works have " proved so beneficial to the place, that there are " several fine cities raised by the riches proceeding " therefrom [14]." He adds, "The trade of making " tin-plates was about sixty years since fixt in Bo- " hemia, and had there long continued; but the " woods decaying, and there being at that time a " wise duke of Saxony, willing and ready to im- " prove his own revenue, and his subjects, did ac- " cept of directions how this trade might be brought " away and fixt in the duke of Saxony's territories [15] " —A Romish Priest, converted to be a Lutheran, " was the chief instrument in the whole affair, until " it was perfected—and a Cornish miner, a Protest- " ant, who had been banished out of England for " his religion, found out the tin in Saxony—both " which persons proved instruments of great wealth " to that duke and country [16]."

The following particulars which I have collected respecting Mr. Yarranton, will justify Bishop Watson in the opinion he has given of him.

He was bound as an apprentice, early in life, to

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[14] Yarranton, part ii. page 176. [15] Ibid. page 178.

[16] Saxony is separated from Bohemia by only a chain of mountains called the *Erzegeberg*; which in German signifies hills that contain mines.

a linen draper, but after some years he left that situation in disgust. In the year 1652 he took some iron works, which he carried on for several years; and during this period he made regular surveys of the three great rivers in England, and by means of associations which were formed by himself, he rendered three other rivers navigable: he studied agriculture with such effect, that many of the arable estates in the midland counties were rendered doubly productive by the new methods of husbandry which he either brought from abroad, or discovered;—he laid a plan for the junction of the Thames and Severn *at that spot* where of late years this very scheme has been effected;—he proposed the cutting of several navigable canals, half a century before any such project had been executed in this country. He made the necessary surveys and planned docks for the cities of London and Dublin:—besides his journey to Saxony already mentioned, he went to Holland, under the patronage of the ancestors of some of our present nobility, to examine the inland navigations of the Dutch, and to investigate the nature of their linen manufactures;—and on his return promulgated the plan for a new manufacture of linens, which he calculated would employ all the poor of England. He published schemes for the improvement of our national fisheries; he made several tours through Ireland, for the express purpose of planting new manufactures and devising the increase of the staple trades of that country: he made a regular survey and estimate of the expense of rendering the

river *Slade* in Ireland navigable, for the purpose of bringing timber down to the coast for His Majesty's navy; and rendered many other signal services to his country.

Notwithstanding Mr. Yarranton had so completely introduced the knowledge of making tin-plate into this country, I do not find that any manufacture of that article was established in these kingdoms until some time between the years 1720 and 1730, which must have been long after Mr. Yarranton's death. The first establishment of this kind was, I believe, fixed in Monmouthshire, where it continued to flourish many years [17].

About the time that this manufactory was established, the amiable and intelligent M. Reaumur, to whom the French are indebted for a new mode of graduating the thermometer, and for many discoveries and improvements in the arts [18],—undertook to discover the method of making tin-plates for the French people. This eminent man, whose mind was cast in a mould very similar to that of Mr. Yarranton, but who possessed more science, never relinquished any thing which he undertook; and accordingly, notwithstanding the innumerable difficulties which he had to encounter, at length suc-

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[17] Upon further inquiry, I find that this was at the town of Ponty Pool; and it is remarkable, that after the lapse of nearly 100 years the manufacture has recently been re-established at the same town on a very extensive scale.

[18] It was Mons. Reaumur who was the means of introducing into France, the methods of making Porcelain. See *Essay on Porcelain*, page 94.

ceeded in acquiring such a knowledge of the principles of the manufacture, as enabled him to instruct several people in the vicinity of Paris, in an art which, until then, had never been practised in that country.

Soon after the time of which I am speaking, several similar manufactories were erected in Great Britain; and now the establishments of this nature are so numerous and extensive in many parts of these kingdoms, that the manufacture of tin-plate is become of great national importance, and more than one hundred thousand boxes of these plates are annually exported.

APPENDIX.

ADDITIONAL NOTES

TO

THE SECOND VOLUME.

NOTES TO ESSAY IX.

ON THE FIXED ALKALIES.

1. *Nitrum.*—Page 6, line 10.

NITRUM or natron was without doubt known to the ancients, though we have no evidence that *nitre* was. In the Proverbs of Solomon, chap. xxv. ver. 20, it is said, that "As he that taketh away a garment in cold weather, and as vinegar upon *nitre*, so is he that sings songs to a heavy heart;" here the word ought certainly to be nitrum or natron, for on this vinegar would occasion a violent effervescence, though not upon salt-petre or nitre. "A memoir on an extraordinary collection of salt-petre, which was made in France during the years 1794 and 1795, also on a new method of refining this salt, by C. A. Prieur," will be found in the *Annales de Chimie*, tome xx. page 298.

An account of a remarkable cave in Kentucky in the United States of America, called *Mammoth Cave*, which contains an extraordinary quantity of salt-petre, may be seen in the *Archæologia Americana*, pages 355—361.

2. *Very corrosive.*—Page 7, line 16.

This alkali in its pure state is so corrosive that it is employed by the surgeons for what is called their *Potential cautery*. Boerhaave relates, that an unfortunate man who fell into a boiling copper of a lixivium of caustic potash, had all the soft parts of his body dissolved, and nothing remained but his bones.—See Dallow's edition of Boerhaave's *Elements of Chemistry*, quarto, vol. ii. page 43. Dreadful accidents have sometimes happened

from persons having swallowed caustic alkali. The late Dr. Johnstone, an eminent physician of Worcester, when writing on this subject remarks, that "it will perhaps require 8 or 10 grains of caustic alkali to destroy texture, for a small quantity would be neutralized by the carbonic acid it meets with in the passage, or by the contents of the stomach itself."—Johnstone on *mineral poisons*, page 150. See also an article under the title of "Causticity" in the Additions to Macquer's *Dictionary of Chemistry*, octavo, vol. iii.

3. *Barilla imported.*—Page 9, line 28.

A gentleman who is just returned from Spain, where he has resided several months, has obtained the following information. "The best barilla usually exported to Ireland grows," he says, "in the neighbourhood of Alicant. It is gathered from the months of August to October. A considerable quantity of the finest quality is sent to Paris, of which their superior crystal glass is made. It is usually purchased in November; and a curious circumstance is connected with the bargain, viz. that though the price be *fixed* when the barilla is received by the merchant, the latter obliges himself to make good any advance which may take place until Christmas-day; so that of course cargoes arrive at their destination, and are disposed of, before their real cost is known. When the crop promises to be scanty, it is necessary to bribe the farmers by anticipated payments. Abundance of barilla is made at Carthagena, and throughout the province of Valentia."

4. *Rendered caustic.*—Page 12, line 7.

As it is important to those who use large quantities of the fixed alkalies to know when a proper quantity of lime has been used to render them caustic—the following directions will probably be acceptable to many individuals. When the solution of caustic alkali is prepared, take a little of the clear liquor in a wine-glass, and breathe into it through a small glass tube, or otherwise add a few drops of a clear solution of subcarbonate of potash; for if there be a redundance of lime, the dissolved earth will absorb carbonic acid from the carbonate of potash or from the human breath, and this will render the liquor turbid. If this treatment should not occasion the liquor to become turbid, it should then be treated with a little lime-water; and if this occasions a turbidness, it shows that the liquor contains carbonated alkali, and consequently has not had a sufficient quantity of lime; whereas, if the lime be in due proportion, the lixivium will suffer no change from the addition of the above tests, nor will it effervesce with acids.

5. *Caustic potash.*—Page 12, line 17.

Directions for preparing caustic potash in a dry state, will be found in Boerhaave's *Elements of Chemistry*, quarto, vol. ii. page 42. Whenever it is necessary to open a bottle of pure alkali, it should be done in a dry air, or near a fire, and then the stopper immediately returned and carefully secured by wax as at first. Directions for the preparation of *pure* potash and soda by means of alcohol are given by Dr. Henry in his *Elements of Experimental Chemistry*, vol. i. page 255. See also Davy, in the *Philosophical Transactions* for 1808, page 355: and the *Essay on Water*, vol. ii. page 366. An account of the method which Lowitz has adopted for obtaining the alkalies of the greatest purity, in a crystallized state, will be found in Nicholson's Quarto *Journal*, vol. i. page 164.

6. *Fern.*—Page 17, line 1.

A chemical friend who has had much experience in the preparation of the fixed alkalies, and who requested that I would allow him the perusal of my Essay on that subject, has sent me the following remarks on what I have said respecting the agency of Fern in milling woollen cloth; and which he attributes not to the alkali which it contains, but merely to its mechanical operation on the cloth. As I should not deal candidly with my readers if I withheld these remarks, I here give them exactly as I have received them. "I entertain strong doubts," says he, "of the juices of fern or any other vegetable plant containing an alkali in a free state, having always considered *incineration* to be an essential process for the development of that salt. I have made several experiments on the kelp weed and other of the fuci, but could never perceive the least trace of free alkali in their expressed juice, although the ashes produced by burning them always gave indications of its presence. These vegetables probably contain neutral salts, (the sulphates of potash and soda for example,) which undergo a decomposition in the fire, and in which their own carbon probably acts as a powerful agent."

7. *Kelp.*—Page 38, line 5.

Jameson states, that barilla contains from 8½ to 23 per cent. of pure alkali divested of water and carbonic acid, and that kelp contains from 2 to 5 per cent. From an analysis which I myself made of three parcels of barilla in the year 1801, one of which was from Alicant, another from Carthagena, and the third from Teneriffe, all of which were at that time esteemed to be the best samples in the London market; I found that 112 lbs. of

the first contained 19 lbs. 2 oz. of pure dry caustic alkali; 112 lbs. of the second contained 22¼ lbs. of alkali; and the Teneriffe 22¾ lbs. which was esteemed much better than is usually brought from that island.

Four parcels of barilla which I examined with great care on the 4th of June 1810, were found to be composed as under. The first parcel consisted of 19 parts pure soda, 22 of neutral salts and carbonic acid, and 59 of insoluble matter. The second parcel gave 18 per cent. of pure alkali, 21 of neutral salts, &c., and 61 of insoluble matter. Another contained 10¾ pure alkali, 24 neutral salts, &c., 65 of insoluble matter, and ¼ loss. The fourth parcel consisted of 11 parts of pure alkali, 20 neutral salts, &c., and 69 of insoluble matter.

Two other samples were analysed on the 1st of February 1813: one of which contained 30¼ per cent. of pure dry soda, 10¾ neutral salts, 9 carbonic acid and 50 insoluble matter. This was the best sample of barilla that I ever recollect to have come under my examination. Kelp is of very various quality; I have seen some which contained 8 per cent. and others which would not yield one per cent. of pure soda. The particulars of the analysis of several parcels of kelp and barilla which I made for the Highland Society of Scotland in the year 1816 will be found in the 5th vol. of the *Transactions* of that Society, page 65, &c.

8. *Kelp ovens.*—Page 39, line 13.

The ovens in which kelp is made are generally of the rudest kind, being nothing more than excavations within the ground, lined with rough unhewn stones. I would earnestly recommend it to the proprietors of our kelp shores to erect one or more reverberatory furnaces similar to those described in the plates which accompany the Essay on the fixed Alkalies; for by means of such furnaces a greater heat would be produced, and the matter might be stirred with greater convenience; and hence there would be a more effectual decomposition of the muriate of soda by means of the vegetable alkali which these plants always furnish in abundance. By such management I apprehend much of the Irish and Scotch kelp might be rendered of double its present value. See the plates No. 16 and 17, and the descriptions given of them at the beginning of this volume.

9. *Soda for glass.*—Page 47, line 16.

Since this paragraph was written, I have investigated the nature of the comparative effects of soda and potash in making glass; and I am now convinced that a *harder* glass may be made

with soda than it is possible to produce from potash only, and that soda therefore ought always to be made choice of for making plate glass. See the Essay on Glass, vol. ii. page 245—248.

10. *Oil soap.*—Page 47, line 20.

It is well known that olive oil produces better soap than any other substance. I am therefore anxious to suggest whether it might not be a desirable thing for Government to encourage the growth of olive-trees in some of the British colonies, or in some favourable district in the British settlements in the East Indies. The oil would in time form an important branch of commerce, especially if enough were produced to supply all our soap-manufactories: and this would render the country more independent of Russia; which is a very important object. A competent opinion of the value of this oil for the manufacture of soap, when compared with others, both vegetable and animal, may be obtained by perusing a memoir in the *Annales de Chimie*, tome xix. pages 289—311. The idea of recommending the cultivation of the olive occurred to me on reading the following passage: "The olive-tree," says Savary, "has almost disappeared from Attica. The Albanians and Turks, who have alternately ravaged Greece, seem to have been intent on destroying it. Within twenty years they cut down two hundred thousand feet of these trees. The island of Crete has not suffered the same fate. The olive-trees, which delight in a sandy soil, a mild temperature, and the vicinity of the sea, grow in abundance on the hills and in the plains. Their produce constitutes the chief wealth of the inhabitants, and their principal branch of commerce. Exclusive of the prodigious consumption of oil by the inhabitants, besides what the Turks of Canea make use of in the manufacture of soap, which they export throughout the Levant, the Turks annually load four-and-twenty ships with oil, containing on an average one hundred and fifty tons each."—Savary's *Letters on Greece*, octavo, 1788, page 381.

11. *Sir Humphry Davy.*—Page 59, line 8.

After this paragraph was printed, I discovered a trifling error in the date which I have given to the first decomposition of the alkalies by Sir H. Davy; for I now perceive that the paper which I mention as having been read before the Royal Society, contained a detail of his *subsequent* experiments, the discovery itself having been announced in the preceding year (1808), and the particulars of it described in the volume of *The Philosophical Transactions* for that year.

12. *Depositories of salt.*—Page 68, line 1.

Notwithstanding these immense masses of salt found in various parts of the world, there are places where salt has never yet been discovered: this is the case in many parts of Africa. Mungo Park relates that "the greatest of all luxuries in the interior of Africa is *salt*. It would," says he, "appear strange to an European to see a child suck a piece of rock salt as if it were sugar. This, however, I have frequently seen; although the poorer class of inhabitants are so very rarely indulged with this precious article, that to say 'A man eats salt with his provisions,' is the same as saying 'He is a rich man.' I have suffered great inconvenience myself from the scarcity of this article. The long use of vegetable food creates so painful a longing for salt, that no words can sufficiently describe it." Park's *Travels into the Interior of Africa*, quarto, 1799. Some persons have imagined that it is an useless and pernicious practice to take salt with our food; but the above testimony seems to decide that question. On looking over a work printed by Kearsley, in small octavo, 1768, I find the following experiment is related: "I put," says the author, "two ounces of milk, warm as it comes from the cow, into a tea-cup with a little common salt. I put the same quantity and of equal warmth into another tea-cup, without salt. Then dropping a very little distilled vinegar into each, a hard curd presently appeared in that milk which had no salt in it, while the other with the salt was scarcely altered."

13. *Salt mines of Poland.*—Page 68, line 3.

"We read of a salt mine in Poland, one mile from Cracow, which is 200 fathoms below the surface, where there were 1000 men constantly employed. In order to descend into this stupendous work, it was customary for the person descending to fasten himself by a cord to the main rope, and then to take another man on his lap. The large rope being then lowered a little, a third person made a seat for himself with a rope fastened to the main rope, taking another on his lap; and being also let down a little way, he gave an opportunity for another pair to fasten themselves in the same way: in which manner thirty, forty, or more people were let down at once; of whom the first having touched the ground at the bottom, steps out and goes aside, the rest following him in regular order and doing the like. Thus they descended to the depth of 100 fathoms; and after passing through several passages they came to certain ladders by which they descended 100 fathoms deeper." *Philo-*

sophical Transactions for 1670, page 1099. In the same volume there is an account of the discovery of a mine of very hard rock salt at Rotherton in Cheshire, upwards of 30 yards below the surface of the earth.

The salt mine above mentioned is at the town of Wielitska, a German mile from Cracow: it is the largest in Europe, and has been constantly worked for more than 600 years: it is eleven hundred feet in width, and 6,700 feet in length. The subterranean passages or galleries are very spacious, and in many of them altars or chapels are hewn out of the salt-rock. In these chapels, crucifixes or the images of saints are set up; and a light is kept continually burning before them. The places where the salt is hewn out of the mine, are called chambers; and some of these are so spacious that a large church might be inclosed in one of them. When candles are brought into these places, the numerous rays of light reflected by the crystals of salt emit a surprising lustre. About 600,000 quintals of salt are annually dug out of these mines. That part of the mine which has been most excavated, and which appears like a vast plain, is interspersed with clusters of huts belonging to the miners and their families, many hundreds of whom are born and finish their lives in this subterranean inclosure.

"There are salt mountains," says Jonston, "in India, particularly at Oxomenus, where it is cut out of quarries like stone; and the custom arising from it is more to their kings than what they receive from gold and pearls." Jonston's *History of Nature*, p. 94.

14. *Decomposition of salt.*—Page 68, line 12.

Several patents having been obtained at different times by various individuals, for their peculiar methods of procuring soda from sea salt, and having myself many years ago devoted much time and expense to the investigation of this subject, I am glad that I have it in my power to furnish my readers with a list of those patents, which at the time were registered among other chemical manuscripts, as being those which appeared to me to possess the most merit.

James King, dated March 4th, - - 1780
Alexander Fordyce, August 1st, - - 1781
Earl of Dundonald, February 28th,- 1795
Robert Hoaksley, July 20th, - - - -1796
George Hodson, February 28th, - - 1797

Mr. Hodson obtained a patent for the same object, which bore date August 30, 1792; but the mode therein described will not effect the desired purpose.

While on the subject of Sea-salt, I embrace the opportunity of mentioning a *new* purpose to which salt has been applied, and which certainly deserves to be registered for the benefit of the public. Some merchants of Liverpool, who in the year 1815 had prepared several hundred carboys of oil of vitriol to be exported to America, had them stowed on board two ships, and filled up all the vacant spaces between the baskets with common salt to prevent the bottles from being broken by the motion of the vessels. Proposals for the insurance of these precious cargoes were sent to Lloyd's, and the circumstance of the stowage in salt was mentioned to induce the underwriters to insure at a lower premium. Some gentleman, however, who knew the effect which would be produced by the affusion of oil of vitriol upon salt, saw the proposals at Lloyd's, and stated that if a single bottle should by any accident become broken on the passage, every individual on board would inevitably be suffocated. It was, however, too late to take any precautionary measures, for the vessels had then both actually sailed. The names of the ships which were then crossing the Atlantic in such a perilous situation were the *Lewis* and the *Margaret*, I believe both of Liverpool. Should either of these vessels have sprung a leak, so as to dissolve much of the salt, the stowage of the carboys would have been loosened, and some of the bottles would unavoidably have been broken, by the rocking of the ship.—Here we have another instance how necessary it is that all classes of society should become acquainted with the elements of chemical science.

15. *Rock salt.*—Page 69, line 3.

It is very important to the curers of provisions to employ the purest salt which they can obtain. This is deemed so necessary, that some of the Irish provision-curers have been in the habit of using *foreign* salt, preferring it chiefly on account of its size and hardness of grain, and imagining that it must on these accounts be better than the English salt for their purpose. It has, however, been proved that the purest and best salt now known is that which is made from the rock salt of Cheshire. It has been usual to dissolve the mineral salt in sea water, and then re-crystallize it; but as sea water besides muriate of soda contains also much muriate and sulphate of magnesia, both which are injurious in the process of curing either flesh or fish, Messrs. Londons of Northwich have obtained a patent for refining rock salt merely by fusing it in a reverberatory furnace. Their salt is therefore without the impurities of sea water, and also without either the water of crystallization or water of adhesion: hence it is superior in its purity, solidity, and magni-

tude of grain, to any imported foreign salt whatever. The samples which I have examined of this salt appear to be very clear, and it has a property which I never observed in any other salt—that it does not decrepitate in the fire. The *bay-salt* imported into this country, and hitherto so much approved for many purposes, is all made by the evaporation of sea-water, and consequently must be extremely impure. The price of common salt in Cheshire, without duty, is 1*l.* per ton; the price of Messrs. Londons' refined salt is 2*l.* per ton.

General Statement of some of the Results of Dr. Henry's valuable Experiments on various Kinds of Common Salt.

1000 Parts by weight of each kind of Salt.	Insol. Matter	Earthy Muriates.	Sulph. Lime.	Sulph. Magnesia.	Total Impurities.	Pure Muriate of Soda.
St. Ubes Bay Salt	9	3	23½	4½	40	960
Oleron Salt	10	2	19½	4¼	35¾	964¼
Scotch Salt from Sea water	4	28	15	17½	64½	935½
Common Lymington Salt	2	11	15	35	63	937
Cheshire crushed Rock	10	0¼	6½	—	16¾	983¼
— forthe Fisheries	1	1	11¼	—	13¼	986¾
— Common	1	1	14½	—	16½	983½
— Stoved	1	1	15¼	—	17½	982½

See Dr. Henry's "Memoir on the Analysis of several Varieties of British and Foreign Salt," in the *Philosophical Transactions* for 1810, page 89.

NOTES TO ESSAY X.

ON EARTHENWARE AND PORCELAIN.

16. *Roman bricks.*—Page 74, line 8.

Brick-making was esteemed an art of great consequence by the ancient Romans; in proof of which the following evidence presents itself. Abdala, the slave who waited on the person of the empress Livia the wife of Augustus, was set over all the slaves that made bricks; and in the year 1738, on exploring the remains of the ancient city of Heraclea, it was observed that one of the bricks bore the name of *Abdala* and also that of his mistress the empress. This appears the more extraordinary, because soon after the time of Augustus a law was enacted, ordaining that no architect should be allowed to affix his name

upon any part of a building which he had erected, even though it should have been built at his own expense.—See *A Description of the first Discoveries of the ancient City of Heraclea*, translated by Wickes Skurray, octavo, 1750, page 58.—Pliny says that "Euryalus and Hyperbius, two brothers, at Athens, caused the first brick- and tile-kiln to be erected, yea and houses thereof to be made; whereas before that time men dwelled in holes and caves within ground. Gellius is of opinion that Doxius the son of Cœlus devised the first houses that were made of earth or clay."—Holland's *Pliny*, vol. i. book vii. page 188.

17. *Water-pipes.*—Page 78, line 19.

Some idea of the state of the potter's art among the ancient Romans may be conceived from the following passage in Pliny. "How beneficial," says he, "is the earth unto us in yielding us conduit-pipes for conveying water, tiles flat yet hooked and made with crotchets at one end to hang upon the sides of the roof, chamfered to lye in gutters to shoot off water, curbed for crests to claspe the ridge on both sides, to say nothing of the vessels that be turned with the wheel and wrought round; yea and great tuns and pipes of earth devised to contain wine and water also! In regard of which Numa ordained at Rome a seventh confraternity of potters."—Pliny's *Natural History*, book xxxv. chap. 12, page 551.

18. *Roman earthenware.*—Page 79, line 16.

A large vessel of Roman earthenware was found during the winter of 1813 at Ambleside in the county of Westmoreland, where it is supposed an old Roman city originally stood. But the most interesting detail that I have met with of their earthen vessels is in the account of the discovery of the ancient city of Heraclea, as described by Marquis Don Marcello di Vinuti, in a work already quoted. "Through a door of white marble," says the marquis, "we came into a room 14 yards long and eight broad, which led into another room of the same length, but almost square. Round the inside of both these rooms there ran along close to the wall, about half a yard high, a kind of bench covered with a marble pavement, which seemed at first sight to have been used for a seat; but on coming to examine it nearer, I perceived on the top some round stones or stopples of marble; which, being removed, I found were the covers of some great *earthen jars*, set in with mortar, the necks of which were inclosed just within the bench. These vessels were of a roundish form, and would hold ten barrels Tuscan measure each.

On one of these vessels was this inscription: OPUS. DOLIARE. VINARIUM. The names which were on the handles and necks of these vessels were the names of the makers. Those wrote with ink were the names of the owners of the liquor contained within; and by reason of the multiplicity of names, it is imagined to have been a cellar for the use of the soldiers who were stationed there to guard the walls; and that whosesoever name was wrote on the vessel, to him belonged the wine contained therein, whether he bought it, or it was his allowance." Skurray's translation of the *Description of the Discoveries at Heraclea*, page 110. We have other evidence that the Romans knew how to make very large vessels in earthenware. Pliny says that "Vitellius, while he was emperor, caused a charger to be made and finished that cost a million of sesterces, for the making whereof there was a furnace built on purpose in the field."—Pliny's *Natural History*, Holland's translation, folio, vol. ii. book xxxv. chap. 12, page 551. I suspect, however, that Pliny must have been misinformed as to the price of this vessel, for a million of Roman sesterces are equal to more than eight thousand pounds of our money.

It is generally believed that the ancient Egyptians had also made great progress in the knowledge of the manufacture of Earthenware. Mons. Belzoni says, "The art of varnishing and baking the varnish on clay, were in such perfection that I doubt if it could be imitated at present," and this remark was the result of his own observations. Belzoni's *Researches in Egypt*, quarto, page 173.

19. *Lapis lazuli.*—Page 81, line 17.

This mineral, says Guyton, "may be urged to a red heat, and even lose 0.2 of its weight, without any visible alteration in its colour; but with a stronger heat, such as that of the furnace of an enameller, its colour changes to gray."—Guyton, *Annales de Chimie*, tome xxxiv. page 58. Mr. Delaval supposes that the colour produced from lapis lazuli was applied to the painting of porcelain, after the ware had undergone the heat of the furnace, and before the introduction of cobalt.—Delaval's *Inquiry ito the Cause of the Changes af Colours in opake and coloured Bodies*, 4to, London 1777, page 58.

20. *Bernard de Palissy.*—Page 90, line 21.

Palissy is said by Fontenelle to have gone as far in the character of a philosopher as genius without learning could carry him. This eminent man, when in his pleasant moments, used to say, in reference to his trade as a potter, that "he had no

property whatever, except heaven and *earth*."—*Nouveau Dict. Hist.* art. PALISSY, viii. page 261. No one can have read the History of the Life of Palissy without wishing to know every thing respecting him. For an account of the books published by him, and of the nature of his writings, the reader may consult Platt's *Jewel House of Art and Nature*, part ii. quarto, London 1594.

21. *A collection of natural history.*—Page 92, line 7.

It may be worth noting, that a very satisfactory view of the importance of the study of natural history may be seen in Mr Stillingfleet's *Calendar of Flora*. The work, which promised to be of the utmost importance in this science, was planned by Mons. Martini of Berlin. It was entitled *An Universal Dictionary of Natural History*. He lived, however, only to finish four volumes; and though these contain nearly 700 pages each, he did not get through the second letter of the alphabet. The author died in 1778, and I am not informed whether the work has ever been continued.

22. *Etruscan vases.*—Page 101, line 19.

A beautiful collection of Engravings of the ancient vases in the British Museum and elsewhere, has been published by Mr. Moses, with dissertations on the vases of antiquity. This superb work is entitled *A Collection of Vases, Altars, Paterae, Tripods, Candelabra, Sarcophagi, &c. from various Museums and Collections, engraved on* 170 *Plates*, by Henry Moses, with historical Essays, quarto, 1814 The most superb work of this kind is Sir William Hamilton's *Collection of Engravings from ancient Vases, mostly of pure Greek Workmanship*. Three imperial folio volumes, Naples 1791—1795.

23. *Clay.*—Page 104, line 5.

Among the different methods of sinking pits to a considerable depth for getting *clay*, there is one practised at Forges (department of the Lower Seine) which deserves to be distinguished for its simplicity and economy.—It escaped me while writing the Essay, but I must not omit to refer to it here. For the detail, see Loysel *sur l'Art de la Verrerie*, page 43.

24. *Decomposed felspar.*—Page 109, line 3.

Felspar in its native state is one of the best materials for glazing porcelain; but the clay which results from it by its decomposition is totally infusible. This circumstance was unaccountable until Vauquelin analysed the felspar, and found that it contained potash. To this therefore must its fusibility be attri-

buted. The following is the analysis which he has given of this mineral:

Silica	62.83
Alumina	17.02
Lime	3
Oxide of Iron . .	1
Potash	13
Loss	3.15
	100.00

It is proper to mention that some persons have objected to the use of felspar when containing its full complement of potash, as a glaze for some sorts of porcelain; because, wherever a glaze contains too much of either of the fixed alkalies, it is apt to contract and expand unequally or in a different ratio from the body of the ware. There is the same inconvenience attending the use of powdered glass for a glaze, which will sometimes either fly off the porcelain, or become cracked in various places on its surface, by sudden change of temperature. For an account of the composition of a glaze employed in China, see *The Philosophical Transactions*, No. 261, page 524.

25. *Form of a cone.*—Page 124, line 20.

When the text was written I was not aware that the potter's ovens which are now built are not *cones*, but are constructed in the form of a cylinder, mounted by a dome.

26. *An unwholesome glaze.*—Page 137, line 16.

In addition to what I have said respecting the danger of using a glaze of lead on any of the articles made in earthenware which are to be employed in preparing condiments for our food, I must add another caution, which is, never to prepare pickles or any thing in which vinegar is used, in jars of cream-coloured ware; for this ware is always glazed with lead, and the lead being soluble in vinegar would impart a poisonous quality to the preparations contained in it. When will the community entertain proper notions respecting the deleterious properties of this insidious poison? In Lancashire I have observed it is a common practice to have brewing-coppers constructed with the bottom of copper, and the whole sides of lead. In the same county the dairies are furnished with milk-pans made of lead; and when I expostulated with some individuals on the danger of this practice, I was told that *leaden* milk-pans throw up the cream much better than vessels of any other kind. In some parts of the north of England it is customary for the

inn-keepers to prepare mint-salad by bruising and grinding the vegetable in a large wooden bowl with a *ball of lead* of twelve or fourteen pounds weight. In this operation the mint is cut, and portions of the lead are ground off at every revolution of the ponderous instrument.

27. *Antimony.*—Page 141, line 13.

The potters generally use the common *sulphuret* of antimony, without being aware of the quantity of sulphur which it contains. As this is the cheapest form in which antimony can be obtained, it answers very well for some purposes; but where fine colours are required, a pure oxide of antimony would probably be preferable, as the presence of so large a portion of sulphur is highly injurious where a beautiful colour is designed to be obtained. The *glass* of *antimony* would surely be preferable to the sulphuret; for Proust has determined that the glass of antimony consists of one part of sulphuret of antimony combined with eight parts of the pure oxide of this metal.

It is well known that a custom has obtained from time immemorial among the Eastern women, of tingeing the eyebrows and eyelashes with some metallic ore to increase their blackness, and it has generally been supposed that this was *antimony*; but from some circumstances mentioned by travellers, particularly the effect which candle-light had upon the colour, I am inclined to believe that the article employed for this purpose was black-lead, and not antimony. See Dr. Shaw's *Travels in Barbary and the Levant*, page 229; Lady M. W. Montague's *Letters*, vol. ii. page 32; and Clarke's edition of Harmer's *Observations on various Passages of Scripture*, vol. iv. page 334.

28. *Printing press.*—Page 144, line 20.

If we consider the many beautiful coins and medals which the ancients produced when the Roman empire was in all its glory; likewise the carnelian and agate seals which they engraved for stamping on soft wax; together with the practice which was very general among that people, of having their names impressed in capital letters on the large earthen jars in which they kept their wine, we cannot avoid being surprised that they never arrived at some method of printing books. An interesting dissertation on this subject may be seen in the *Philosophical Transactions*, No. 450, p. 388; or in Baddam's *Memoirs of the Royal Society*, vol. x. p. 459. Procopius, in his *Hist. Arcana*, says, that the Emperor Justin, not being able to write his name, had a thin piece of board, through which were cut holes in form of the four first letters, which was laid on the

paper, and served to direct the point of his pen. For the date of the origin of printing on paper, see the 1st vol. of these Essays, p. 3.

29. *Crucibles and retorts.*—Page 149, line 6.

The Indians of Louisiana form their culinary utensils with clay mixed with a sort of calcined mica. Of this composition they also make crucibles capable of enduring the strongest heat they can produce. The galena, which is found there in abundance, is fused in these crucibles, by exposing it to a strong heat, in a sort of furnace made by excavating a bank of earth, and forming a chimney through the top of the cave to produce a strong draught of air. The lead thus obtained is employed only for the purpose of sinking their fishing nets.

There are remains of many ancient potteries in the neighbourhood of Salem in the United States, on the shore of lake Erie. On the Ohio and Mississippi, they are found of a more recent era. In the ancient sepulchral barrows, vessels are found equal to any now manufactured in any part of the world. Two covers of vessels were found in Ross county highly polished and made of a calcareous breccia; fragments of these were examined by my friend Professor Silliman, of Yale College, Connecticut; and were found to be equal in texture and execution to vessels of a similar material now manufactured in Italy. See *Archæologia Americana*, vol. i. pages 219—227.

Directions for coating and preserving stone ware retorts are inserted in *The Repertory of Arts and Manufactures*, vol. i. page 310.

30. *Old pottery.*—Page 149, line 23.

The introduction of old ground pottery into the manufacture of stone chemical vessels was a great improvement; but I am surprised to see how near the ancients were to making this discovery. Pliny says, "There is means found to make a strong kind of mortar or cement by the broken sheards of potters' vessels, if the same be ground into powder and tempered with lime, and the ordering it in this manner causeth it to be more firm and last the longer, and such they call *signina*." The more one reads of this author, the more astonished one is at the extent and variety of his knowledge. Pliny's *Natural History*, vol. ii book xxxv. chap. 12, p. 551.

31. *Ancient walls.*—Page 155, line 5.

For information relative to the use of volcanic tarras as employed by the ancients for making their cast vaults and walls, I would recommend to the reader, the perusal of a small vo-

lume entitled *An Account of some German Volcanoes and their Productions*, by R. E. Raspe, London, octavo, 1776, page 124, &c ; also *A Dissertation on the Roman Walls in Britain*, in the Appendix to the second volume of Henry's *History of Great Britain*, octavo, page 469 ; and *The History of the Roman Wall which crosses the Island of Britain*, by W. Hutton, second edition, octavo, London 1813.

NOTES TO ESSAY XI.

ON GLASS.

32. *Coloured glass.*—Page 175, line 11.

STRABO, who visited Alexandria in the first century, was told by the workmen there, that their country afforded an ingredient without which coloured glass could not be made. *Strabo*, lib. xvi. page 758. There is in the British Museum a mummy of great antiquity which is covered with beads of coloured glass. According to Seneca, coloured glass has been made in Europe for more than 2000 years. " Democritus," says he, " brought into Europe the method of making coloured glasses, and thereby counterfeiting gems." Seneca's *Epistles*, 90.

33. *Manganese.*—Page 190, line 9.

For a further explanation of the action of the black oxide of manganese in purifying flint glass, consult the article " Glass" in Aikin's *Chemical Dictionary*, or Loysel *Sur l'Art de la Verrerie*, page 168, § 101. When too much of this oxide has been employed, so as to occasion a purple colour in the glass, it is usual for the workmen to thrust a piece of wood into the mass of melted metal, which quickly abstracts the colour. This oxide imparts its colour to glass only when it is in a high state of oxidizement: the wood therefore becoming carbonized abstracts a part of the oxygen, and the colour of the glass disappears.

34. *Virgil's glass mirror.*—Page 190, line 2.

This must have been an uncommon utensil at the time in which Virgil lived, for in that age and long afterwards mirrors were usually metallic. Job describes the heavens as a molten looking-glass ; and by the order of Moses the brazen laver of the priests was manufactured with the mirrors of the women assembling at the tabernacle. *Exodus*, chap. xxxviii. verse 8. Valerian made the Emperor Probus a present of a silver cup,

the inside of which was cut into mirrors. Pliny and Seneca relate that every young woman in their times expected to have a silver mirror. *Pliny*, book xxxiv. chap. 17. Indeed the mirror-makers of Rome, who were generally silversmiths, were so numerous that they were formed into a company. If any thing further were wanting to prove that the most ancient mirrors were metallic, a circumstance might be mentioned which is recorded by Martial, of a lady in ancient Rome who knocked down her hair-dresser with the mirror, because he had not put her hair into that form which she preferred. The mirrors of the present day are in fact all metallic, and indeed they would be of little use if it were not for the metallic coat at the back of them. For a method of laying tinfoil upon the backs of mirrors, see *Encyclopédie, ou Dictionnaire Universel, Supplement*, tome vi. page 654.

"The ancient inhabitants of some parts of North America employed mirrors of isinglass (*mica membranacea*), which were made of great thickness. Had they been otherwise, they would not have reflected the light. Such mirrors have been found in fifty different barrows in that country." *Archæologia Americana*, vol. i. page 225.

35. *Technical terms.*—Page 191, line 23.

The technical terms in the glass trade are most of them taken from the Italian or French, but some are derived from the German language. *Pontilla* is from the Italian, meaning any thing drawn to a point or derived from a point. *Cavelletta*, the head or crown of the reverberatory furnace, is also from the Italian. *Schrower* is the room at the end of the lier, where the goods are received when annealed; this is from the German. *Fraiche* is the iron pan in which the glass is placed to be cooled or annealed. *Parcellas* is a kind of pincers with a spring back, which is in constant use in those houses where flint glass is made. These terms are all still employed by the glass-makers of Great Britain.

36. *The diamond*—Page 220, line 4.

There is something very mysterious respecting the action of the diamond in cutting glass. Any person observing the certainty and apparent ease with which a skilful glazier performs that operation, would imagine it to be no more difficult than to rule lines upon paper with a pen or a pencil. There is, nevertheless, scarcely a single manual operation within the compass of the ordinary arts, which requires a more delicate sleight of hand. But the most curious circumstance attending it is, that if the surface of the pane of glass be cut or scratched with the

diamond, the glass will not break in the exact line which the diamond has marked, but the fracture will be irregular, and the pane in all probability spoiled; whereas an experienced cutter will divide a sheet of glass into as many squares as he has occasion for, without imprinting any visible mark whatever on the surface; though, if the sheet of glass be examined before it is actually broken into its intended divisions, it will be seen that it is entirely cut through except at the *uppermost* surface.

Not being able to account for this singular circumstance, I consulted a gentleman of considerable acquirements, one of the proprietors of the Tyne window-glass works; and he very obligingly furnished me with the following remarks on the subject: "It is necessary," says he, "that the diamond should be of a regular rhomboidal form; or, at least, that it should have one regular smooth edge and rhomboidal point, of which the angles must be well defined and of a particular degree of acuteness. A diamond, or spark as it is called, which happens to be rather large will rarely answer on this account, its angles being generally too obtuse.

"It is only at one particular point that the diamond will produce a cut; and this point depends on so nice a degree of obtuseness or acuteness in the angles forming the extreme point and ridge, that it can be only guessed at before trial upon the glass itself. Any deviation of the diamond from one particular position and inclination to the surface of the glass, occasioned by the minutest variation of the hand, will entirely prevent the cut. It may appear singular, but it is a fact, that in this respect the *ear* is the cutter's sole guide. He judges by a peculiar creaking of the glass, as the fracture therein pursues the course of the diamond, if its inclination be correct; otherwise he varies it till he finds it, and pursues it by the same means to the end of the cut. He cannot leave off in the middle, not being able to reproduce a cut at the very point where his diamond first comes in contact with the glass, nor of course to depend on the fracture passing out of one into the other line. If this peculiar creaking sound be not produced, the effect is only a scratch upon the surface, such as is made by the diamonds set for the purpose of merely writing upon glass; and it is in vain to expect the fracture to follow the course of this line.

"Where the cut is perfectly good, it should be an *internal* fracture unaccompanied with any scratch, or any visible impression upon the surface whatever; for, in proportion as any such superficial injury is produced, the completeness of the internal fracture is diminished. This fracture, therefore, which is called a *cut* from its resemblance thereto in its effect, as also in the similarity of its appearance to a real cut produced on any other

substance by a sharp-edged instrument, but which has closed again, (the expression being further countenanced by the sharp form of that part of the diamond which comes in contact with the glass,) is really no cut at all, nor does the diamond so much as enter the surface.

"The reason why the internal fracture is imperfect in proportion as the surface is injured, appears to be, that the injury of the surface is nothing else than the dislocation, in small conchoidal fragments, of such particles as the diamond comes successively in contact with, by which its perpendicular pressure is eluded, or dissipated laterally in producing those small excavations or fractures, taking a direction immediately back to the surface.

"The diamond, apparently, wears down its cutting point by long use, though it will stand the work of an ordinary glazier for many years; and the change at last is not visible to the eye, and only apparent by its being no longer fit to produce a cut. No endeavour hath hitherto succeeded in forming an artificial cutting point; which is not to be wondered at, since we know that a change of form not perceptible to the eye is sufficient to destroy the effect.

"The breakage made, even at the manufactories, by the most practised cutters, arising from the delicacy necessary to be observed in the use of this instrument, is very considerable; and that made by glaziers in general, who being less practised operate with timidity, is much more so. It was, therefore, very natural that attention should be directed to the means of giving this operation a mechanical precision; but nothing successful was attained till about the year 1814, when letters patent were granted for instruments by which this object is at once carried to perfection. By the use of one of these instruments, a person not at all accustomed to a diamond may produce a perfect cut, over a table of glass so uneven in its surface that the most skilful workman with a common glazier's diamond would not be able to produce a cut of any kind upon it. This consists in giving the diamond perfect play, and at the same time affording it such guides and support as effectually prevent it from being affected by the unsteadiness of the hand or unevenness of surface, in respect of its inclination to the plane of the table; whereby the diamond, being once well set or mounted in its carriage, becomes equally certain in the hands of every person.

"This patent instrument is now sold upon constructions variously modified by Henry Hammond and Co. at their window-glass warehouse, No. 127, High-Holborn, these persons being principally interested in the patent right."

Having examined some of these patent instruments myself, I think it right to say that the invention appears to me to be very ingenious, and that this or some other instrument constructed upon a similar principle will supersede the diamonds in common use. This little implement was invented by an ingenious watch-maker in Leicestershire, of the name of Shaw, who was led to the consideration of the subject by the desire of affording some assistance to a relative who is a glazier, and who, in consequence of a paralytic affection of the hand, had found a difficulty in cutting his glass by the usual method.

Since the first publication of these remarks, Dr. Wollaston has made some experiments on cutting with the diamond, and has read a paper on the subject to the Royal Society. He found how extremely difficult it is for a person unaccustomed to the use of a diamond, to cut with it. He says, "Although I could tear the surface to a considerable depth, I could by no means command the direction of the fracture." The Doctor's paper, which contains much curious matter, will be found in the *Philosophical Transactions* for 1816, vol. cvi. pages 265—269. It is entitled "On the Cutting Diamond." It was read to the Society on the second of May 1816.

NOTES TO ESSAY XII.

ON BLEACHING.

37. *A fuller.*—Page 338, line 5.

The anecdote to which I allude in this note is told by Apuleius at great length. The substance of it is this: that the fuller unexpectedly bringing home a friend to sup with him at the instant when the wife was engaged with her gallant, she, on the sudden alarm, hides him in a wicker apparatus which had just been employed to bleach garments by the fumes of burning sulphur.—*Contegit viminea cavea; quæ lacinias circumdatas, suffusa candulo fumo sulfuris, inalbabat.* Presently, while they are at supper, the gallant, stifled with the fumes, sneezes aloud; the fuller removes the coop, and the poor panting half-smothered culprit is discovered. Apuleius *De Asino aureo*, edit. Scriverii, Amst. 1624, lib. ix. p. 136.

38. *A line of coloured threads.*—Page 350, line 8.

In recommending the practice of running a line or two of

fast-dyed coloured threads along one of the edges of all calicoes, dimities, &c. it may appear that I advised the adoption of this method on *printed* as well as on *plain* calicoes; I therefore embrace the opportunity which this Appendix affords me, of distinctly stating, that the expedient to which I refer can never be of any use for *printed* cottons, neither had I them in my mind when I gave the recommendation, because I well know that the varied processes to which white calicoes are usually submitted by the printer, would inevitably destroy the indigo blue and probably the Turkey red line also. It can be of use, as a test of good bleaching, only on such goods as are intended to remain white.

NOTES TO ESSAY XIII.

ON WATER.

39. *Green vegetable matter.*—Page 388, line 14.

"THE transition," says Sprengel, "of one organical kingdom of nature into the other, and the impossibility of separating the two by an exact line of demarcation, becomes obvious to those who, with Needham, Priestley, and Ingenhousz, have observed the metamorphosis of the animalcula infusoria into real confervæ. To make this experiment, no particular infusions are required; a vessel filled with pump-water, and exposed to the sun, without being agitated, is sufficient for the purpose. First of all, a delicate green covering is seen to be formed on the surface of the water, consisting of numberless and infinitely minute molecules, that manifest animal motion; these, after some time, disappear, and are transformed into vegetable filaments, which, like all green surfaces of plants, yield oxygen gas when exposed to the influence of the sun." Sprengel's *Introduction to the Study of Cryptogamous Plants*, octavo, London 1810.

40. *Lead an insidious poison.*—Page 286, line 10.

In the province of Poitou there was formerly a disease called the colic of Poitou: but this is no longer common either in France or Germany, since the laws of these countries have made the adulteration of wine with lead, punishable by death. A similar disease was prevalent in the counties of Hereford, Gloucester and Worcester, when leaden utensils were employed in making cider. Dr. Baker, who was physician to Her late Majesty, the Queen of George III., relates that this disease was

likewise prevalent in the cider districts of Devonshire, and that on inquiry he found the stones which compose the circular trough in which the apples are ground, to be cramped together by iron, with melted lead poured into the interstices; and also that many cider presses were to be seen which were lined entirely with lead. Dr. Saunders actually procured 4½ grains of lead from 18 quarts of Devonshire bottled cider.—See *An Essay on the Endemial Colic of Devonshire*, by George Baker, M.D. London 1767. Dr. Franklin has stated, that leaden-worms were formerly used at Boston in America, for the distillation of rum, and that such disorders were produced in consequence of this practice, that the Government found it expedient to enact a law forbidding the use of any worms for stills except such only as were made of pure tin. Some interesting observations on the danger of employing leaden vessels for holding water, or for culinary purposes, will be found in Dr. Lambe's *Essay on the Properties of Spring Water*, 8vo, 1803.

41. *The fullers in ancient Rome.*—Page 378, line 18.

The inhabitants of Rome, except the lower orders of people, generally wore white woollen garments, but especially at public festivals. Ovid *Fasti* i. 79. This made fullers as necessary as laundresses. They were for the most part slaves, but sometimes free; for an inscription in the collection of Fabrettus, c. 4. page 333, mentions the *Collegium Fullonum*, the *Fullers' Company* at Rome. The place where the fullers worked was generally in the fields, on account of the offensive nature of their business. Hence *Plautus Asin.* V. ii. 57.

It appears, from the testimony of ancient writers, that the fullers first threw the clothes into water, where they trod them with their feet. Hence, as Horapollo, *Hieroglyphics*, i. 65, has observed, the Egyptians expressed a fuller by the representation of two human feet in water. This washing by treading with the feet, the Romans called *Consilium, à Consiliendo.* In order to provide themselves with urine, the fullers placed earthen pitchers at the corners of the streets. See Martial xii. 58.

The clothes, having been thus repeatedly trodden upon in water and urine, were laid upon a block and beaten with staves or battledors. It was with one of these, according to a fragment of Hegesippus preserved by Eusebius, that the Jews beat the Apostle James the younger until he died. When the clothes had been trodden and beaten, they were hung up for the water to drain from them. They then scoured them with fullers' earth and a portion of nitre: after this they fumigated them with sulphur; then they carded them with a sort of thistle, and last of

all they applied chalk in some way or other to brighten the colour, as Pliny says xxxv. 17. *Veros autem et pretiosos colores emollit cimolia, et quodam colore exhilarat contristatos sulphure.*

Schoettgenio *On the ancient Methods of Fulling*. See also *The present State of the Republic of Letters*, vol. i. page 150.

42. *Expansion of water.*—Page 415, line 6.

It has been observed that stone buildings are generally most decayed on that side which faces the north. I think this may be attributed to the expansion of the water within the stone during the act of freezing. Thus the external stones of bridges become saturated with water when the river rises just before the commencement of a very severe frost; and when the river subsides, the water within their pores suddenly freezes, and this action bursts the stone in all directions. Aware of this effect of frost, the proprietors of the Strand-bridge, over the Thames at London, have chosen Scotch granite, which being impervious to water can never be injured in this way.—The other three large bridges in the metropolis are built with Portland stone, and these are all rapidly decaying.

43. *Processes of decoction, distillation, &c.*—Page 433, line 14.

Steam has long been employed for the purposes of evaporation and distillation in the laboratory belonging to the Apothecaries' Company of London; and very lately its use has been considerably extended, and a more complete apparatus for effecting a great variety of processes of solution, evaporation, and distillation, by the agency of steam, has been erected. This extensive apparatus was constructed by Mr. Mainwaring under the direction of W. T. Brande, Esq., who has furnished me with the following description of the whole:

The steam laboratory is a brick building lighted from above, about 50 feet long, lofty and well ventilated by apertures in the roof. The steam is supplied from two boilers placed in buildings separate from the laboratory; the largest of which is of the common waggon shape, made of copper, and calculated for the supply of a six-horse steam engine. It is furnished with a float-stone, which acts by means of a lever upon an index placed in the laboratory for the purpose of showing the level of the water; with a mercurial gauge indicating the pressure of the steam, which is usually worked at between 7 and 8 inches; and with a safety valve which opens whenever the pressure exceeds that which is capable of supporting 12 inches of mercury in the syphon. A forcing-pump is also annexed to the boiler,

by which it is occasionally supplied with hot water resulting from the condensation of the steam in the various vessels.

The main steam pipe, which is 6 inches in diameter, is conducted round the laboratory in a cavity of brick-work covered by moveable cast-iron plates, and is accompanied by a smaller pipe, which receives and conveys the water resulting from the condensation of the steam into a cistern properly supplied with valves, whence it is occasionally pumped back into the boiler. A small steam pipe with a register-cock passes to each of the stills and evaporators, each of which also sends off a condensed liquor-pipe into the main for its reception.

The boilers and evaporators are twelve in number: 4 are of pewter, 1 of iron, and 7 of copper. Four of these are capable of holding from 150 to 300 gallons; four contain about 100 gallons; and four from 10 to 20 gallons: there are also some smaller vessels of the same kind, generally used as water baths.

The stills are seven in number: of these the largest contains 500 gallons, and has a distinct worm-tub; two contain 200 gallons each, and one contains 150 gallons; these are of copper. There is also a pewter still of about 30 gallons, and one of lead for the distillation of ether. These 5 stills have two condensing tubs. Lastly, there is a still which with its head and worm are entirely of stone-ware; it is chiefly employed for distilling spirit of nitric ether.

With the exception of the leaden ether-still, all the above vessels are heated by the circulation of steam upon their exterior, being coated with cast-iron jackets, and having a space between the two of about half an inch diameter, into which the steam passes from the main by the register cocks, and from which the condensing pipes pass off. A blow-cock is attached to each vessel, to allow of the escape of the air when the steam is first turned on.

The other boiler above adverted to is calculated for the production of high-pressure steam, with a pressure of 100 lbs. on the square inch; it is applied in another part of the building to various purposes of evaporation, solution, decoction, &c., and in addition only supplies the ether still in the steam laboratory, which is heated by a coil of leaden pipe by which the temperature requisite for the production of ether from alcohol and sulphuric acid is obtained. The waste steam of these boilers is condensed into a large cistern of water in another part of the building.

Independent of the saving of fuel in consequence of the employment of steam as above described, there result from it other more important advantages, such as safety from fire in the

distillation of spirituous and ethereal preparations; prevention of burning or of empyreuma in the evaporation of extracts; and exclusion of the dust and smoke which fires under the separate vessels would necessarily occasion.

Besides the distillatory and evaporatory apparatus, there are also two large drying stoves heated by steam, and several wooden and other vessels for saline solutions, &c. which are occasionally adapted to the steam apparatus, and heated by an immense coil of leaden pipe.

This lengthened description of the apparatus at Apothecaries' Hall has been given for the purpose of showing the great economy of using steam in all the common operations of a chemical laboratory. Another expedient for evaporating heavy or viscous fluids with safety and economy, has also been lately introduced, which consists in making oil at a high temperature the medium by which the heat is conveyed.

In the refining of sugar, great inconvenience had arisen from the circumstance of the sugar being usually boiled by a naked fire, which generally burns a part of the sugar, and occasions a portion of the remainder to be converted into molasses, which is more a product of the fire than a natural educt from the raw sugar. In consequence of this, Mr. Daniel Wilson invented a mode of boiling sugar in coppers without fire-places, merely by forcing heated whale-oil through a coil of metallic pipes lying in the midst of the syrup within the boiler.

For a full account of this important apparatus, which in my opinion might be employed with great advantage in many processes besides that of refining sugar, the reader is referred to an octavo volume entitled *A Report of the Trial of the Action brought by Messrs. Severn, King and Co. against the Imperial Insurance Company, before Lord Chief Justice Dallas and a Special Jury*, &c. and to some papers of mine in the 20th, 21st, and 23d Numbers of the *Journal of Science, Literature and the Arts*, edited at the Royal Institution of Great Britain. The uses of the several parts of the Apparatus will be easily understood by referring to the Plate No. III. and to the "General Explanation of the Plates" in this volume.

NOTES TO ESSAY XIV.

ON SAL-AMMONIAC.

44. *Known to the ancients.*—Page 437, line 2.

It was not until after the Essay on Sal-ammoniac was printed, that I became acquainted with Professor Beckmann's opinion respecting the pretended antiquity of this salt. My readers must however now be informed, that this learned man has asserted that the sal-ammoniac of the ancients was nothing more than impure marine salt. He acknowledges the name is old; but, says he, "as those who, in consequence of the name, considered the *alumen* of the ancients to be our alum, and their *nitrum* to be our salt-petre, were in an error, we should be equally so were we to consider their sal-ammoniac to be the same as ours." Dioscorides and Pliny speak of sal-ammoniac in some places as though it were common salt; but Pliny says also that it was found in the dry sandy deserts of Africa, as far as the oracle of Ammon; and on the other side of the question, Columella, in a prescription for the eye, recommends *rock-salt*, either Spanish, *Ammoniacal*, or Cappadocian.—See Beckmann's *History of Inventions and Discoveries*, London 1814, vol. iv. page 360. Sal-ammoniac was however most certainly known in the 15th century, as Agricola describes it as a salt entirely dissipated in the fire, and as employed in the production of a celestial blue colour; and Biringoccio, who wrote in 1540, recommends nitric acid prepared with sal-ammoniac for dissolving gold.

45. *Uses of ammonia.*—Page 445, line 16.

In addition to the list of uses of ammonia which I have enumerated, I wish to notice that a modern traveller has related the case of an Indian who was bitten by a rattle-snake, and perfectly cured in a few days by the external and internal use of volatile alkali alone, although the poor creature lay at the point of death, and betrayed the most dreadful symptoms. The writer recommends the trial of the volatile alkali also for the cure of hydrophobia. "If (says he) the poison which is communicated by the bite be of an *acid* nature, no remedy can be more efficacious, nor exert a more direct action on the destruction of this poison, than ammonia, which would neutralize the animal acid; but hitherto, I believe, the experiment has not been made."—*Travels in South America* by Don Felix di Azara, 4 volumes octavo, Paris 1809.

46. *Animal bones.*—Page 446, line 23.

"Having seen," says Van Braam, "a pretty large vessel go by, laden with the bones of animals, I was desirous of knowing for what purpose they were intended; and was told that they are to be burnt, and that the cinders are to be put on the ground sown with rice, when the plant is about a foot high, and before the water is let into the fields."—Van Braam's *Embassy to the Court of the Emperor of China*, vol. ii. page 147. There are few refuse articles which afford a better manure than bones; but I should be glad to know whether the Chinese have discovered a method of procuring carbonate of ammonia from them. I am persuaded that no animal matter whatever ought to be despised by the maker of sal-ammoniac: especially if his manufactory is situated in a country where mineral coal is not to be procured: even the oldest and the driest bones will yield a considerable quantity of ammonia.

NOTES TO ESSAY XV.

ON EDGE TOOLS.

47. *Instruments of stone.*—Page 472, line 8.

In the 1st volume of the *Transactions of the American Antiquarian Society*, an antique axe-head is described, made of a species of green stone equal to Ægyptian granite and polished in the neatest manner. In the same work mention is made of a fish-spear, with six or seven long prongs, perfectly separated and barbed, carved out of calcedony. It is difficult to conceive how such instruments could have been made even by means of steel instruments. Page 230.

48. *Gold and silver.*—Page 477, line 13.

The lavish employment of these precious metals by the ancients is recorded by all the early historians. A few instances may be adduced. The first anchors were not made of iron, but of stone, and sometimes of wood. These latter were loaded with lead. Several writers relate that the Phœnicians, in their first voyages into Spain, having amassed more silver than their ships could contain, took the lead from their anchors, and supplied its place with silver. Goguet's *Origin of Laws*, &c. vol. i. page 292 Diodorus says that "the tomb of King Simandius was environed with a circle of gold three hundred and sixty-five

cubits about, and a foot and a half thick." "Semiramis erected in Babylon three statues of gold, one of which was forty feet high and weighed a thousand Babylonian talents. For these statues there was a table or altar of gold, forty feet long and twelve feet broad, weighing fifty talents." Cogan's *Diodorus Siculus*, folio, pages 34 and 76. We read that Solomon received 666 talents of gold (more than 27 tons weight) in one year. 1 *Kings*, ch. x. ver. 14. The historian proceeds to relate that "all his drinking-vessels were of gold, and all the vessels of the house of the forest of Lebanon were of pure gold, none were of silver; it was nothing accounted of in the days of Solomon." *Ibid.* verse 21. Herodotus informs us that the Scythians placed cups of pure gold in the sepulchres of their kings. We are also told by Pliny, that his contemporaries employed the precious metals in great abundance for ornamenting their horses and carriages. Nero and his Empress shod their favourite horses with gold and silver.

A very remarkable instance of profusion in the use of gold is recorded in a letter from Paul Demidoff, Esq. at Petersburg, to Mr. Peter Collinson, dated September 17th, 1764, and is preserved in the 2nd volume of the *Archæologia*. "In the desert which constitutes the southern boundary of Siberia at 50 North latitude, between the rivers Irtish and Obalet, are many tumuli or barrows, where the borderers have long been in the practice of digging for treasures. The Russian court," says Mr. Demidoff, "being informed of these depredations, sent a principal officer, with sufficient troops, to open such of these tumuli as were too large for the marauding parties to undertake, and to secure their contents. This officer, on taking a survey of the numberless monuments of the dead spread over this great desert, concluded that the barrow of the largest dimensions most probably contained the remains of the prince or chief: and he was not mistaken; for, after removing a very deep covering of earth and stones, the workmen came to three vaults, constructed of stones, of rude workmanship; of which a view is exhibited in the engraving. That wherein the prince was deposited, which is the centre, and the largest of the three, was easily distinguished by the sword, spear, bow, quiver, and arrow which lay beside him. In the vault beyond him, towards which his feet lay, were his horse, bridle, saddle, and stirrups. The body of the prince lay in a reclining posture, on *a sheet of pure gold*, extending from head to foot, and *another sheet of gold*, of the like dimensions, was spread over him. He was wrapt in a rich mantle bordered with gold, and studded with rubies and emeralds. His head, neck, breast, and arms naked, and without

any ornament. In the lesser vault lay the princess, distinguished by her female ornaments. She was placed reclining against the wall, with a gold chain of many links, set with rubies, round her neck, and gold bracelets round her arms. The head, breast, and arms, were naked. The body was covered with a rich robe, but without any border of gold or jewels, and was laid on a *sheet of fine gold*, and covered over with another. The four sheets of gold weighed 40lbs. The robes of both looked fair and complete; but, on touching, crumbled into dust." See "An Account of certain Tartarian Antiquities," with a copperplate engraving of the barrow containing the Prince and Princess with their habiliments, &c.—*Archæologia*, vol. ii. page 222.

49. *Obelisks of porphyry.*—Page 479, line 7.

Diodorus relates, that "at the entrance of the sepulchre of King Simandius was a gate of porphyry 480 feet long, and 672 feet high." Cogan's *Diodorus Siculus*, page 32. Lord Valentia relates, that "at Axum are the ruins of a great number of obelisks, some of which have been sculptured, while others have not. The beautiful one which remains erect has been very incorrectly delineated by Bruce; but Mr. Salt, who was attracted to it by its grandeur, has given an elegant drawing of it. Though nearly 80 feet high, it is formed of a single block of granite, curiously carved, and in excellent proportions. No decisive opinion can be formed of its antiquity." Lord Valentia's *Voyages and Travels to India, Ceylon, the Red Sea, Abyssinia, and Egypt*, 3 vols. quarto, London 1809.

There are three celebrated obelisks of porphyry in Egypt, called the Needles of Cleopatra. One of these is at Grand Cairo, the other two at the eastern end of the palace in the city of Alexandria. There are also ancient porphyry busts of several of the Roman Emperors still preserved in the palace of the Thuilleries at Paris. On the porphyry pillars of Egypt, and on the methods which it has been supposed the ancients adopted in cutting and polishing porphyry, the following works may be consulted. Dr. Lister in the *Phil. Trans.* No. 203. Dr. Robert Huntington in the *Phil. Trans.* No. 161, page 624; or Baddam's *Memoirs of the Royal Society*, vol. ii. page 286. Birch's *History of the Royal Society*, vol. i. page 238, and vol. ii. page 73. Boyle's *Works abridged by Shaw*, vol. i. page 111. Da Costa's *Natural History of Fossils*, page 285.

50. *Art of forming copper.*—Page 481, line 20.

We may know that the Anglo-Saxons had acquired the art

of working in brass and copper, from an incident which the historian has related of King Edgar. It was the custom in his time, that a whole company drank out of a single vessel, which was handed from one to another. "To prevent quarrels, King Edgar," he says, "commanded the drinking-vessels to be made with knobs of brass on the inside at certain distances from each other; and decreed that no person, under a certain penalty, should either drink himself, or compel another to drink, at one draught, more than from one of these knobs to another." *William of Malmesbury*, book ii. page 31.

When the ancients employed copper for making weapons of war, they hardened the metal by an admixture of tin. Many such instruments are still preserved in the cabinets of the curious. See Nicholson's quarto *Journal*, vol. i. page 468.

51. *War-chariot.*—Page 482, line 3.

The Britons and ancient Greeks and Romans were not the only people who employed chariots in the field of battle. Appian, an historian eminent for fidelity, relates that the army of Ptolemy Philadelphus king of Egypt consisted of 200,000 foot, 40,000 horse, 300 elephants, and 2000 armed chariots. See Dr. Gillies's *History of the World*, 2 vols. 4to, London 1808. In the time of Diodorus Siculus, our ancestors in Britain used chariots in the field of battle. See his *History*, chap. vii. page 235. Mr. Pegge, however, asserts that these were differently constructed from those used at Troy. See "Observations on the Chariots, &c. of the ancient Britons," *Archæologia*, vol. vii. article 24.

52. *Imperial foundries.*—Page 482, line 22.

What has been said of the foundries which were established in this country by the Romans for making iron might be confirmed, if there were any doubt of the fact, by a circumstance which occurred about forty years ago in Wales, near the town of Brecknock. In October 1783, as some labourers were felling a tree, the roots of which tore up the earth, some small pillars were presented to view. It afterwards appeared that these belonged to a Roman work consisting of three baths; one hot, the two others cold. The state of this curious relic is described by Mr. Hay, who has also given a good engraving of it. In one of the passages to the baths was found a bar of *malleable iron*, four feet long. See *Archæologia*, vol. vii. At this period few persons in Europe were acquainted with a method of making cutting-instruments either of iron or steel; for it is related that the inhabitants of the northern countries of Europe believed

that swords were made by certain pygmies who were concealed in the mountains. Bergman's *Physical Essays*, vol. iii. p. 89.

53. *First made in London.*—Page 485, line 7.

As many centuries have elapsed since our ancestors learnt the art of making armour and offensive weapons of steel, it seems extraordinary that so long a period should have intervened before they acquired the method of making the most useful implements of common life in that metal. It has already been shown that table-knives were not fabricated in London until the year 1563; and it is related by Stowe, that needles were not sold in Cheapside until the reign of Queen Mary, and then they were made by a Spanish Negro, who refused to discover the secret of his art.

Even the pin was not known in England till towards the middle, or latter end, of the reign of Henry VIII.; the ladies until then using ribbons, loops, skewers made of wood, of brass, silver, or gold. At first the pin was so ill made, that in the 34th year of the king, parliament enacted that none should be sold unless they be "double-headed, and have the headdes soudered faste to the shanke of the pynne," &c. But this interference had such an influence on the manufacture, that the public could obtain no supply until the obnoxious act was repealed. On referring to the Statute Book, I find that the act of repeal, which passed in the 37th year of the same reign, contains the following clauses, which tend to show how cautious the Legislature ought to be not to interfere with any manufactory which they do not perfectly understand. The act of repeal having recited the former act, it then goes on to say, "At which tyme the pynners playnly promised to serve the kynges liege people wel and sufficiently, and at a reasonable price. And for as much as sens the makying of the saide act there hath ben scarcitee of pynnes within this realme that the kynges liege people have not ben wel nor competētly served of such pynnes nor ar like to be served nor the pynners of this realm (as it doeth nowe manifestly appere) be hable to serve the people of this realme accordyng to their saied promise. In consideracion whereof it maie please the kyng, &c. that it maie be adjudged and demed from hensforthe frustrate and nihilated and to be repealed for ever." *Stat. Henrici Octavi* xxxvii. cap. 13.

54. *Damascus swords.*—Page 523, line 8.

The sabres of Damascus have given rise to a curious art in the working of iron and steel called *Damaskeening*, which con-

sists in making incisions therein and filling those up with gold or silver wire. This process is employed chiefly in enriching sword blades, and the locks of pistols. Dr. Rees in the *Cyclopædia* vol. xi. has described the method by which this artificial damasking is effected, and which I think worth transcribing.

"The name which this art bears, shows the place of its origin, or at least the place where it has been practised in the greatest perfection, viz. the city of Damascus in Syria; though M. Felibien attributes the perfection of the art to his countryman Cursinet, who wrought under the reign of King Henry IV.

Damaskeening is partly mosaic work, partly engraving, and partly carving: as mosaic work, it consists of pieces inlaid; as engraving, the metal is indented or cut in creux; and as carving, gold and silver are wrought therein in *relievo*.

There are two ways of damaskeening; in the first, which is the most beautiful, the artists cut into the metal with a graver and other tools proper for engraving on steel, and afterwards fill up the incisions or notches with a pretty thick silver or gold wire. In the other, which is only superficial, they content themselves to make hatches, or strokes across the iron, &c. with a cutting knife, such as is used in making small files. As to the first, it is necessary the gravings or incisions be made in the dove-tail form, that the gold or silver wire, which is thrust forcibly into them, may adhere the more strongly. As to the second, which is the more usual, the method is this: Having heated the steel till it changes to a violet or blue colour, they hatch it over and across with the knife, then draw the ensign or ornament, intended, on this hatching, with a fine brass point or bodkin. This done, they take fine gold wire, and conducting or chasing it according to the figures already designed, they sink it carefully into the hatches of the metal with a copper tool." Some of this work is very durable and extremely beautiful. See pages 523—525, and page 543 of this volume.

55. *Metallic baths.*—Page 526, line 2.

The following Tables having been constructed from actual experiment, for the purpose of enabling the working cutler to prepare various kinds of metallic baths, I am desirous of prefacing them with a few words explanatory of the methods I pursued in making the experiments.

In order to conduct these experiments with as much accuracy as possible, I procured two bright iron ladles capable of holding four ounces of water each. In one of these the mixed metals were melted; and when the alloy was completely fused and

thoroughly mixed, it was poured into the other ladle *, and a thermometer graduated to 620° immersed in it. As the melted compound cooled, the thermometer progressively fell: this motion was carefully watched, and at the moment when the mercury ceased to sink, the degree at which the instrument stood was accurately noted down, as the point of fusion of that particular alloy. The same plan was followed in every instance: and there was the less difficulty in doing this, because it usually happened that the mercury sunk with great regularity while the melted metal was in the act of cooling and still in a fluid state, until it stopped altogether; and at that moment the mercury was observed to rise one degree †. This evidently noted a change in the state of the metal, and appeared to me to be the exact point which ought to be noted as the degree of temperature at which complete fusion ceases and the state of solidity commences.

The Table No. I. was constructed from the results of the first set of experiments with tin, lead, and bismuth; those No. II. and III. show the melting points of several compounds made with tin and lead only. These last alloys will prove more useful to the working cutler, because such baths can be constructed cheaper than those which contain bismuth, and the melting points are generally higher.

TABLE, No. I.

A new Table of the different Temperatures at which the following Metallic Compounds, made with Bismuth, Lead, and Tin, respectively melt.

Parts of metal by weight.	Parts of metal.	Parts of metal.	Degrees of Fahrenheit.
8 bismuth,	5 lead, and	3 tin	melt at 202
8 bismuth,	6 lead,	3 tin	208
8 bismuth,	8 lead,	3 tin	226
8 bismuth,	8 lead,	4 tin	236
8 bismuth,	8 lead,	6 tin	243

* Although this ladle was not put over the charcoal fire like the other in which the metals were melted, care was taken to keep it hot, that it might not chill the fluid alloy too much when it was poured into it.

† The bulb of the thermometer was always put into the *centre* of the melted mass, and in no case was allowed to go to the bottom of it so as to touch the iron ladle, lest this should not cool in the same gradation as the fluid metal.

Parts of metal by weight.	Parts of metal.	Parts.	Degrees of Fahrenheit.
8 bismuth,	8 lead,	and 8 tin melt at	254
8 bismuth,	10 lead,	8 tin	266
8 bismuth,	12 lead,	8 tin	270
8 bismuth,	16 lead,	8 tin	300
8 bismuth,	16 lead,	10 tin	304
8 bismuth,	16 lead,	12 tin	294
8 bismuth,	16 lead,	14 tin	290
8 bismuth,	16 lead,	16 tin	292
8 bismuth,	16 lead,	18 tin	298
8 bismuth,	16 lead,	20 tin	304
8 bismuth,	16 lead,	22 tin	312
8 bismuth,	16 lead,	24 tin	316
8 bismuth,	18 lead,	24 tin	312
8 bismuth,	20 lead,	24 tin	310
8 bismuth,	22 lead,	24 tin	308
8 bismuth,	24 lead,	24 tin	310
8 bismuth,	26 lead,	24 tin	320
8 bismuth,	28 lead,	24 tin	330
8 bismuth,	30 lead,	24 tin	342
8 bismuth,	32 lead,	24 tin	352
8 bismuth,	32 lead,	26 tin	348
8 bismuth,	32 lead,	28 tin	332
8 bismuth,	32 lead,	30 tin	328
8 bismuth,	32 lead,	32 tin	320
8 bismuth,	32 lead,	34 tin	318
8 bismuth,	32 lead,	36 tin	320
8 bismuth,	32 lead,	38 tin	322
8 bismuth,	32 lead,	40 tin	324

TABLE, No. II.

A new Table of the different Temperatures at which several Metallic Compounds made with Tin and Lead only, *respectively melt.*

Parts.		Parts.		Temp.
4 tin	and	4 lead	melt at	372°
5 tin		4 lead		352
6 tin		4 lead		336
7 tin		4 lead		338
8 tin		4 lead		340
9 tin		4 lead		344
10 tin		4 lead		348

Parts.		Parts.		Temp.
11 tin	and	4 lead	melt at	352°
12 tin		4 lead		356
13 tin		4 lead		360
14 tin		4 lead		362
15 tin		4 lead		364
16 tin		4 lead		367
17 tin		4 lead		370
18 tin		4 lead		372
19 tin		4 lead		375
20 tin		4 lead		378
22 tin		4 lead		380
24 tin		4 lead		382
4 lead		4 tin		372
5 lead		4 tin		390
6 lead		4 tin		412
7 lead		4 tin		420
8 lead		4 tin		442
9 lead		4 tin		460
10 lead		4 tin		470
11 lead		4 tin		476
12 lead		4 tin		482
13 lead		4 tin		486
14 lead		4 tin		490
15 lead		4 tin		494
16 lead		4 tin		498
17 lead		4 tin		502
18 lead		4 tin		505
19 lead		4 tin		509
20 lead		4 tin		512
21 lead		4 tin		515
22 lead		4 tin		517
23 lead		4 tin		518
24 lead		4 tin		519
25 lead		4 tin		520
26 lead		4 tin		523
27 lead		4 tin		525
28 lead		4 tin		527
29 lead		4 tin		529
30 lead		4 tin		530
32 lead		4 tin		532
34 lead		4 tin		535
36 lead		4 tin		538
38 lead		4 tin		540

Parts.		Parts.		Temp.
40 lead	and	4 tin	melt at	542°
42 lead		4 tin		544
44 lead		4 tin		546
46 lead		4 tin		548
48 lead		4 tin		550
50 lead		4 tin		551
52 lead		4 tin		552
54 lead		4 tin		554
56 lead		4 tin		555
58 lead		4 tin		556
60 lead		4 tin		557
62 lead		4 tin		557
64 lead		4 tin		557
66 lead		4 tin		557
68 lead		4 tin		557
70 lead		4 tin		557
100 lead		4 tin		558
Pure lead melts at				612

The following Table, marked No. III., consists chiefly of a selection from the aforesaid alloys, of such mixtures as appear to me to be suitable for certain purposes of the working cutler. Such manufacturers, therefore, will need only to look in the Table for the name of the edge tool which they have occasion to temper, and opposite thereto they will find the proportion of each metal that is necessary to form a bath for tempering that particular instrument. When the alloy is in use, a quantity of tallow or grease ought to be put with it; as this will swim upon the melted mass, and prevent the oxidation of the metals. When the process of tempering is finished, the metallic alloy should always be marked with the number that is attached to it in the Table, as this will prevent mistakes in the selection of the baths for future operations.

No. III.

A new Table of the Composition of Metallic Baths for the Use of Working Cutlers.

No.	Edge Tools to be tempered in the various Baths.	Composition of the Bath.	Temper. Fahren.
1	Lancets, in a Bath composed of	7 lead 4 tin	420°
2	Other surgical instruments	7½ lead 4 tin	430
3	Razors, &c.	8 lead 4 tin	442
4	Penknives and some implements of surgery	8½ lead 4 tin	450
5	Larger penknives, scalpels, &c.	10 lead 4 tin	470
6	Scissars, shears, garden hoes, cold chisels, &c.	14 lead 4 tin	490
7	Axes, firmer chisels, plane-irons, pocket-knives, &c.	19 lead 4 tin	509
8	Table-knives, large shears, &c.	30 lead 4 tin	530
9	Swords, watch-springs, &c. ..	48 lead 4 tin	550
10	Large springs, daggers, augers, small fine saws, &c.	50 lead 2 tin	558
11	Pit-saws, hand-saws, and some particular springs	Boiling linsd oil	600
12	Articles which require to be still somewhat softer	Melting lead	612

In making the experiments which laid the foundation of the Tables No. II. and III. several curious anomalies were observed which deserve particular notice. Tin itself melts at the temperature of 440° of Fahrenheit, pure lead at 612°, but a mixture of equal weights of these two metals, as will appear by the inspection of the Table No. II., became fusible at 372°; with the addition of one part more of tin the compound melts at 352°, and another part of tin added to the former mixture renders the whole fusible at 336°; but after this, every addition of tin, though this is the more fusible metal of the two, renders the compound still more and more infusible.

In entering upon the second course of experiments for Table II., I began, as before, with four parts of lead and four of tin; but instead of increasing the tin as in the first series, I suffered that to remain the same, and made an addition of lead for each

new experiment; and this, as might have been expected, had the effect of increasing the degree of temperature of the melting point at every fresh addition of the lead, until I attained the temperature of 557°, when the further additions of lead made no alteration in the fusibility of the compound.

Having endeavoured in vain to account for this very singular anomaly, I at last imagined that owing to the large quantity of lead, compared with tin, which was exposed to the fire, at every melting, as much lead might each time be converted to an oxide as was equal to the new lead perpetually added, and that this might occasion the alloy to be more fusible than was expected. Therefore, to put this suspicion to the test, I emptied the ladle entirely, and took fresh portions of both the metals in the proportions of 70 of the one and 4 of the other. Here I was surprised to find that the fusing point was still 557°. I then melted 100 parts of lead with 4 of tin; but in this case the fusing point appeared to be rather under 558°, whereas on leaving out the 4 parts of tin and immersing the thermometer in lead only, the mass always began to congeal when the mercury in the instrument had sunk to 612°.

Before I close this subject, I wish to remark that several writers have differed very much in their accounts of the point at which lead becomes fusible. Sir Isaac Newton states it to be 540°, Dr. Lewis *near* 540°, Cloud* 548°, Morveau 590°, Irvine and Guyton 594°, Dalton 610°, and Crichton 612°. This disparity has been occasioned, as I apprehend, by some of these eminent experimentalists having employed lead of an impure quality; because I found that a very minute portion of tin increases its fusibility in a surprising degree.

This effect of tin upon lead I discovered very soon after I began these experiments; and therefore, to ensure the purity of the lead, I procured some for myself by the reduction of litharge; and I can venture to state with confidence that the fusing point of lead is 612°, as that which I obtained in the way above mentioned would not melt until it had acquired that temperature.

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* Memoir by Mr. Joseph Cloud, assayer of the Mint in the United States, entitled "An Attempt to ascertain the fusing Temperature of Metals," in the *Transactions of the American Philosophical Society*, New Series, vol. i. page 169.

A TABLE

OF THE

EQUIVALENT NUMBERS

OF

VARIOUS SUBSTANCES,

MOST OF WHICH ARE MENTIONED IN THESE ESSAYS.

Substances.	Equivalent Number.	Composition.
Acid acetic	48	?
—— arsenic	66.5	Arsen. 44 + oxy. 22.5
—— arsenious.....	59	Arsen. 44 + oxy. 15
—— benzoic	112	?
—— boletic.....	?	
—— boracic.....	20	Boron 5 + oxy. 15
—— camphoric	?	
—— carbonic	20.7	Carb. 5.7 + oxy. 15
—— chloric.....	71	Chlor. 33.5 + oxy. 37.5
—— chloriodic	151.25	Iod. 117.75 + chl. 33.5
—— chlorocarbonic	46.7	Chlor. 33.5 + carb. oxide 13.2
—— chlorocyanic	57.9	Chlor. 33.5 + cyan. 24.4
—— chromic	43.5	Chr. 28.5 + oxy. 15
—— citric (dry)	55.8	Carb. 22.8 + oxy. 30 + hyd. 3

Substances.	Equivalent Number.	Composition.
Acid citric crystallized	72.8	Cit ac. 55.8 + water 17
—— columbic.....	146.5	Col. 139 + oxy. 7.5
—— ferrocyanic	?	
—— fluoboric	20. ?	Fluor. 15 + boron 5.
—— fluoric	16 ?	Fluor. 15 + hyd. 1
—— gallic	59.7	Carb. 34.2 + oxy. 22.5 + hyd. 3
—— hydriodic.....	118.75	Iod. 117.75 + hyd. 1
—— hydrocyanic	25.4	Carb. 11.4 + nit. 13 + hyd. 1
—— hydrophosphorous ..	45.5	Phos. ac. 37 + water 8.5
—— hypophosphorous	14.75 ?	?
—— hyposulphuric	33.75 ?	Sulph. 15 + oxy. 18.75 ?
—— hyposulphurous	22.5 ?	Sulph. 15 + oxy. 7.5 ?
—— iodic.....	155.25	Iod. 117.75 + oxy. 37.5
—— lactic	?	} Composition unknown.
—— malic	66 ?	
—— meconic	21 ?	
—— molybdic.....	66.5	Moly. 44 + oxy. 22.5
—— molybdous	59	Moly. 44 + ox. 15
—— muriatic	34 5	Chlor. 33.5 + hyd. 1
—— nitric, dry	50.5	Nitrog. 13 + oxy. 37.5
—— ——, liquid (sp.gr.1.50)	67.5	Nitr. acid 50.5 + water 17
—— nitrous.....	43	Nitrog. 13 + oxyg. 30
—— oxalic	35.5 ?	
—— —— crystal^{d}, 4 waters	69.5	Oxal. acid 35.5 + water 34

Substances.	Equivalent Number.	Composition.
Acid oxychloric	66.0	Chlo. 33.5 + oxyg. 52.5
—— oxyodic	155.25	Iodine 117.75 + oxy. 37.50
—— phosphoric.....	26	Phosp. 11. + oxy. 15
—— phosphorous	18.5	Phosp. 11. + oxy. 7.5
—— prussic	25.4	Carb. 11.4 + nitr. 13. + hyd. 1
—— saccholactic	?	Composition unknown.
—— selenic.....	52.5	Selenium 37.5 + oxy. 15
—— sorbic	same as malic.	Composition unknown.
—— suberic	?	
—— succinic	47.3	Carbon 22 8 + oxy. 22.5 + hyd. 2
—— sulphuric (dry)	37.5	Sulp. 15 + 22.5 oxy.
————liquid(sp. gr. 1.85)	46	Sulp. ac. 37.5 + water 8.5
—— sulphurous	30.	Sulph. 15 + oxyg. 15
—— tartaric	62.5	?
—— tungstic	112.5	Tung. 90 + oxy. 22.5
—— uric	33. ?	Composition unknown.
—— zumic	?	
Alumium	16.5	
Alum (dry)	243	Sulph. alumin. 123 + bisulp. pot. 120
—— crystallized (25 waters)	430	Alum. dry 243 + water 187
Alumina	24	Alumium 16.5 + oxyg. 7.5
—— acetate	72	Alumina 24 + ac. acid 48
—— sulphate	61.5	Ox. alum. 24 + sulp. acid 37.5
Ammonia	16	Nitrog. 13 + hyd. 3

Substances.	Equivalent Number.	Composition.
Ammonia acetate.....	64	Amm. 16 + acet. ac. 48
—— arseniate.....	82.5	Amm. 16. + ars. ac. 66.5
—— benzoate.....	128	Amm. 16 + ben. ac. 112
—— carbonate	36.7	Amm. 16 + carb. ac. 20.7
—— bicarbonate.....	57.4	Amm. 16 + carb. acid 41.4
—— chlorate	87	Amm. 16 + chlor. acid 71
—— chromate.....	59.5	Amm. 16 + chrom. acid 43.5
—— citrate	71.8	Amm. 16 + citr. acid 55.8
—— muriate	50.5	Amm. 16 + mur. acid 34.5
—— nitrate	66.5	Amm. 16 + nitr. ac. 50.5
—— oxalate.....	51.5	Amm. 16. + oxal. ac. 35.5
—— phosphate	42	Amm. 16 + phos. ac. 26
—— phosphite	34.5	Amm. 16 + phos. ac. 18.5
—— succinate.....	63.3	Amm. 16 + suc. acid 47.3
—— sulphate	53.5	Amm. 16 + sulp. ac. 37.5
—— sulphite	76	Amm. 16 + sulp. ac. 60
—— tartrate	78.5	Amm. 16. + tart. ac. 62.5
Antimony	45	
—— chloride	78.5	Antim. 45 + chlor. 33.5
—— iodide	162.7	Antim. 45 + iod. 117.5
—— oxide 1st.	52.5	Antim. 45 + oxy. 7.5
—— oxide 2nd.	60	Antim. 45 + oxy. 15
—— sulphate	90	Oxid. antim. 52.5 + sulp. ac. 37.5
—— sulphuret.....	60	Antim. 45 + sulp. 15

Substances.	Equivalent Number.	Composition.
Antimony, oxalate of	88	Ox. ant. 52.5 + ox. ac. 35.5
—— phosphate	78.5	Ox. ant. 52.5 + ph. ac. 26
—— phosphuret.....	56	Ant. 45 + phosp. 11
—— tartrate	115	Ox. ant. 52.5 + tar. ac. 62.5
Arsenic	44	
—— acid	66.5	Ars. 44 + oxyg. 22.5
—— chloride	111	Ars. 44 + chlorine 67
—— muriate	128	Oxy. ars. 59 + mur. ac. 69
—— white oxide.....	59.0	Ars. 44 + oxyg. 15
—— sulphuret	59	Ars. 44 + sulphur 15
Azote.....	13	
Barium	65.0	
—— chloride	98.5	Bar. 65 + chlorine 33.5
—— iodide	182.7	Barium 65 + iodine 117.7
—— oxide	72.5	Bar. 65 + oxyg. 7.5
—— peroxide	80.0	Bar. 65 + oxyg. 15.0
—— phosphuret.....	76	Bar. 65 + phosp. 11
——sulphuret	80	Bar. 65 + sulphur 15
Barytes	72.5	Bar. 65 + oxyg. 7.5
—— acetate	120.5	Bar. 72.5 + ac. ac. 48
—— arseniate.....	139.0	Bary. 72 5 + ars. acid 66.5
—— arsenite	131.5	Bary. 72.5 + arsen. ac. 59
—— benzoate	184.5	Bar. 72.5 + benz. ac. 112

Substances.	Equivalent Number.	Composition.
Barytes, borate of	92.5	Bar. 72.5 + bor. acc. 20
—— camphorate	?	
—— carbonate	93.2	Barytes 72.5 + carb. ac. 20.7
—— chlorate	143.5	Bar. 72.5 + chlo. ac. 71
—— chromate.....	116	Bary. 72.5 + chr. ac. 43.5
—— citrate	128.3	Bar. 72.5 + cit. ac. 55.8
—— fluate	88.5	Bary. 72.5 + fluor. acid 16
—— gallate.....	132.2	Bar. 72.5 + gal. ac. 59.7
—— hydrate	81.0	Bar. 72.5 + water 8.5
—— —— crystallized ..	242.5	Bar. 72.5 + water 170
—— hydriodate	191.2	Bar. 72.5 + hyd. ac. 118.7
—— iodate	227.75	Bar. 72.50 + iod. ac. 155.25
—— malate.....	138.5	Bar. 72.5 + mal. ac. 66
—— molybdate	139	Bar. 72.5 + mol. ac. 66.5
—— muriate	107	Bar. 72.5 + mur. ac. 34.5
—— nitrate.....	123	Bar. 72.5 + nit. ac. 50.5
—— —— crystallized	140	Nitr. Bar. 123 + water 17
—— oxalate.....	108	Bar. 72.5 + ox. ac. 35.5
—— phosphate	98.5	Bar. 72.5 + phos. ac. 26
—— phosphite	91	Bary. 72.5 + phos. ac. 18.5
—— phosphuret.....	76	Barium 65 + phosphorus 11
—— seleniate.....	125	Bary. 72.5 + sel. acid 52.5
—— silicate.....	?	
—— succinate.....	119.8	Bar. 72.5 + suc. ac. 47.3

Substances.	Equivalent Number.	Composition.
Barytes, sulphate of	110	Bar. 72.5 + sulp. ac. 37.5
—— sulphite	102.5	Bar. 72.5 + sulp. ac. 30
—— sulphuret	80	Barium 65 + sulphur 15
—— tartrate	135	Bar. 72.5 + tar. acid 62.5
—— tungstate.....	185	Bar. 72.5 + tung. acid 112.5
—— urate	105.5	Bar. 72.5 + ur. ac. 33
—— zumate	?	
Bismuth	66.5	
—— acetate.....	122	Ox. bis. 74 + ac. ac. 48
—— arseniate	140.5	Ox. bis. 74 + ar. ac. 66.5
—— chloride	100	Bismuth 66.5 + chlorine 33.5
—— citrate	129.8	Ox. bism. 74 + citr. ac. 55.8
—— iodide	184.2	Bism. 66.5 + iod. 117.7
—— nitrate	124.5	Ox. bism. 74 + nitr. acid 50.5
—— oxalate.....	129.5	Ox. bis. 74 + oxal. ac. 55.5
—— oxide	74	Bis. 66.5 + oxy. 7.5
—— sulphate	111.5	Ox. bis. 74 + sulp. acid 37.5
—— sulphuret	81.5	Bism. 66.5 + sulphur 15
—— tartrate	136.5	Ox. bis. 74. + tar. acid 62.5
Borax	49.5	Soda 29.5 + bor. acid 20
Boron.....	5	
Calcium.....	19	
—— chloride	52.5	Calcium 19 + chlor. 33.5

Substances.	Equivalent Number.	Composition.
Calcium, fluoride of	34	Calc. 19 + fluorine 15
—— iodide	136.7	Calc. 19 + iodine 117.7
—— oxide	26.5	Calc. 19 + oxyg. 7.5
—— phosphuret.....	30	Cal. 19 + phos. 11
—— sulphuret	34	Cal. 19 + sulp. 15
Calomel	223.5	Mercury 190 + chlorine 33.5
Carbon	5.7	
—— hydrochloride	46.9	Chlo. 33.5 + olef. gas 13.4
—— perchloride.....	111.9	Carb. 11.4 + chlor. 100.5
—— protochloride.....	39.2	Carb. 5.7 + chlorine 33.5
—— oxide	13.2	Carb. 5.7 + oxy. 7.5
—— phosphuret.....	16.7	Carb. 5.7 + phosphorus 11
—— sulphuret	35.7	Carb. 5.7 + sulp. 30
Carburet of nitrogen	24.4	Carb. 11.4 + nitrog. 13
Carburetted hydrogen	6.7	Carb. 5.7 + hyd. 1
Chloride of nitrogen	147	Nitr. 13. + chl. 134
Chlorine	33.5	
Chloric ether	46.9	Chlor. 33.5 + olef. gas 13.4
—— —— acid.....	71	Chlor. 33.5 + oxyg. 37.5
Chromium	28.5	
—— —— 1st oxide	36	Chrome 28.5 + oxyg. 7.5
—— —— 2nd oxid (acid)	43.5	Chrome 28.5 + oxyg. 15
Citrate of ammonia.....	71.8	Citr. ac. 55.8 + amm. 16
—— barytes.....	128.3	Citr. ac 55.8 + barytes 72.5

Substances.	Equivalent Number.	Composition.
Citrate of bismuth	129.8	Cit. ac. 55.8 + ox. bismuth 74
—— cobalt	93.8	Cit. ac. 55.8 + ox. cobalt 38
—— copper.....	186.6	Cit. ac. 111.6 + ox. cop. 75
—— iron	89.3	Cit. acid 55.8 + ox. iron 33.5
—— lead	160.3	Cit. acid 55.8 + ox. lead 104.5
—— lime	82.3	Citr. ac. 55.8 + lime 26.5
—— magnesia	74.3	Citr. acid 55.8 + mag. 18.5
—— manganese.....	91.8	Citr. acid 55.8 + ox. mang. 36
—— mercury	253.3	Citr. acid 55.8 + ox. merc. 197.5
—— nickel	91.3	Citr. ac. 55.8 + ox. nic. 35.5
—— potash	100.8	Citr. acid 55.8 + pot. 45
—— silver	165.8	Citr. acid 55.8 + ox. silv. 110
—— soda.....	85.3	Citr. ac. 55.8 + soda 29.5
—— strontites	107.8	Citr. acid 55.8 + stron. 52
—— tin..	118.8	Citr. ac. 55.8 + ox. tin 63
—— zinc	96.3	Citr. ac. 55.8 + ox. zinc 40.5
Cobalt	30.5	
—— arseniate.....	104.5	Ox. cob. 38 + ars. ac. 66.5
—— citrate.....	93.8	Ox. cob. 38 + citr. acid 55.8
—— oxalate	73.5	Ox. cob. 38 + oxal. ac. 35.5
—— oxide	38	Cobalt 30. + oxygen 7.5
—— sulphate	75.5	Ox. cob. 38 + sulp. ac. 37.5
—— tartrate	100.5	Ox. cob. 38 + tar. acid 62.5
Columbium	139	

Substances.	Equivalent Number.	Composition.
Columbate of potash	191.5	Col. acid 146.5 + potash 45
Copper	60	
—— acetate	171	Ox. copp. 75 + acet. acid 96
—— carbonate	95.7	Ox. copp. 75 + carb. acid 20.7
—— citrate	186.6	Ox. copp. 75 + citr. acid 111.6
—— muriate	144	Ox. copp. 75 + m. ac. 69
—— nitrate	176	Ox. cop. 75 + n. ac. 101
—— oxalate of	146	Ox. cop. 75 + ox. ac. 71
—— & ammonia, oxalate of	197.5	Oxalate cop. 146 + oxal. am. 51.5
—— & potash, oxalate of ..	226.5	Oxalate cop. 146 + ox. potash 80.5
—— & soda, oxalate of....	211	Oxalate cop. 146 + oxal. soda 65
—— oxide	67.5	Copp. 60 + oxyg. 7.5
—— —— 2nd	75	Cop. 60 + oxy. 15
—— perarseniate	208	Ox. cop. 75 + ars. ac. 133
—— protarseniate	134	Ox. copp. 67.5 + ars. ac. 66.5
—— sulphate	150	Ox. cop. 75 + sulp. ac. 75
—— —— crystallized	235	Ox. cop. 75 + s. a. 75 + wat. 85
—— sulphite	105	Ox. cop. 75 + sul. ac. 30
—— succinate	114.8	Ox. copp. 67.5 + suc. acid 47.3
—— tartrate	200	Ox. cop. 75 + tar. acid 125
Corrosive sublimate	257	Mercury 190 + chlorine 67
Cyanogen	24.4	Carb. 11.4 + nitr. 13
Diamond	5.7	

Substances.	Equivalent Number.	Composition.
Fluoboric gas	20	Fluorine 15 + bor. 5
Fluorine.....	15	
Glucinum	20	
Glucina	27.5	Glucinum 20 + oxygen 7.5
Gold	97	
—— chloride	130.5	Gold 97 + chlorine 33.5
—— muriate	139	Ox. gold 104.5 + mur. ac. 34.5
—— nitrate	155	Ox. gold 104.5 + n. acid 50.5
—— oxide	104.5	Gold 97 + oxygen 7.5
—— phosphuret.....	108	Gold 97 + phosphorus 11
—— sulphuret.....	127	Gold 97 + sulphur 30
Gum	85	
Gummate of lead.....	274.5	Gum 170 + oxide lead 104.5
Hydrofluoric acid	16	Fluorine 15 + hydrogen 1
Hydrophosphoric gas.....	13	Phosp. 11 + hyd. 2
Hydrogen	1	
—— carburetted.....	6.7	Carbon 5.7 + hydrogen 1
—— phosphuretted	12	Phos. 11 + hyd. 1
—— sulphuretted	16	Sulp. 15 + hyd. 1
Iodine.....	117.75	
Iron.....	26	
—— acetate.....	81.5	Oxide iron 33.5 + acet. acid 48

Substances.	Equivalent Number.	Composition.
Iron, carbonate of	54.2	Oxide iron 33.5 + carb. ac. 20.7
—— 1st chloride	59.5	Iron 26 + chlorine 33.5
—— 2nd chloride	76.25	Iron 26 + chlorine 50.25
—— chromate.....	77	Ox. ir. 33 5 + chr. ac. 43.5
—— citrate	89.3	Ox. ir. 33.5 + citr. ac. 55.8
—— gallate.....	93.2	Ox. iron 33.5 + gal. ac. 59.7
—— muriate	68	Ox. iron 33.5 + mur. ac. 34.5
—— permuriate	89	Ox. iron 37.25 + mur. ac. 51.75
—— nitrate.....	84	Ox. iron 33.5 + nitr. acid 50.5
—— pernitrate	113	Ox. ir. 37.25 + n. acid 75.75
—— oxalate.....	69	Ox. iron 33.5 + ox. ac. 35.5
—— oxide	33.5	Iron 26 + oxyg. 7.5
—— peroxide	37.25	Iron 26 + oxygen 11.25
—— phosphate	59.5	Ox. iron 33.5 + ph. acid 26
—— phosphuret	37	Iron 26 + phosp. 11
—— succinate.....	80.8	Ox. iron 33.5 + suc. acid 47.3
—— sulphate (dry)	71	Ox. iron 33.5 + sulp. acid 37.5
—— —— crystal^{d}(7waters)	130.5	Dry s. iron 71 + water 59.5
—— sulphuret	41	Iron 26 + sulphur 15
—— bisulphuret.....	56	Iron 26 + sulp. 30
—— perarseniate	137	Ox. iron 37.25 + ars. acid 99.75
—— protarseniate	100	Ox. iron 33.5 + ars. ac. 66.5
—— tartrate	96	Ox. iron 33.5 + tar. acid 62.5

Substances.	Equivalent Number.	Composition.
Lead	97	
—— acetate	152.5	Ox. lead 104.5 + acet. acid 48
—— arseniate	171	Ox. lead 104.5 + ars. acid 66.5
—— benzoate	216.5	Ox. lead 104.5 + ben. acid 112
—— carbonate	125.2	Ox. lead 104.5 + carb. ac. 20.7
—— chlorate	175.5	Ox. lead 104.5 + chlor. ac. 71
—— chloride.....	130.5	Lead 97 + chlorine 33.5
—— chromate	148	Ox. lead 104 5 + chr. ac. 43.5
—— citrate	160.3	Ox. lead 104.5 + citr. acid 55.8
—— gallate	164.2	Ox. lead 104.5 + gallic acid 59.7
—— nitrate	155	Ox. lead 104.5 + n. ac. 50.5
—— subnitrate.....	259.5	Ox. lead 209 + nit. ac. 50.5
—— oxalate	140	Ox. lead 104.5 + oxal. ac. 35.5
—— oxide 1st	104.5	Lead 97 + oxy. 7.5
—— —— 2nd	108.25	Lead 97 + oxy. 11.25
—— —— 3rd	112	Lead 97 + oxy. 15.0
—— phosphate.....	130.5	Ox. lead 104.5 + ph. ac. 26
—— phosphite	123	Ox. lead 104.5 + ph. ac. 18.5
—— phosphuret	108	Lead 97 + phos. 11
—— succinate	151.8	Ox. lead 104.5 + suc. acid 47.3
—— sulphate	142	Ox. lead 104.5 + sulp. ac. 37.5
—— sulphite.....	134.5	Ox. lead 104.5 + sulp. ac. 30
—— sulphuret	112	Lead 97 + sulphur 15
—— tartrate	167	Ox. lead 104.5 + tar. ac. 62.5

Substances.	Equivalent Number.	Composition.
Lead, tartrate of, and potash	274.5	Ox. lead 104.5 + tar. ac. 125 + pot
Lime	26.5	Calcium 19 + oxyg. 7.5
—— acetate	74.5	Lime 26.5 + ac ac. 48
—— arseniate	93	Lime 26.5 + ars. ac. 66.5
—— benzoate	138.5	Lime 26.5 + benzoic acid 112
—— borate	46.5	Lime 26.5 + bor. ac. 20
—— carbonate	47.2	Lime 26.5 + carb. ac. 20.7
—— chlorate	97.5	Lime 26.5 + chlor. acid 71
—— chromate	70	Lime 26.5 + chr. ac. 43.5
—— citrate	82.3	Lime 26.5 + citric acid 55.8
—— hydrate	35	Lime 26.5 + water 8.5
—— hydriodate	145.2	Lime 26.5 + hyd. acid 118.7
—— malate	92.5 ?	Lime 26.5 + malic ac. 66
—— muriate	61	Lime 26.5 + mur. ac. 34.5
—— nitrate	77	Lime 26.5 + nitr. ac. 50.5
—— oxalate	62	Lime 26.5 + oxalic ac. 35.5
—— oxyiodate	181.75	Lime 26.5 + oxyod. acid 155.25
—— phosphate	52.5	Lime 26.5 + phos. ac. 26
—— biphosphate	78.5	Lime 26.5 + phos. ac. 52
—— succinate	73.8	Lime 26.5 + suc. acid 47.3
—— sulphate	64	Lime 26.5 + sulp. acid 37.5
—— —— crystallized	81	Sulp. lime 64 + water 17
—— sulphite	56.5	Lime 26.5 + sulp. acid 30
Lithia	16.5	Lith. 9 + oxyg. 7.5

Substances.	Equivalent Number.	Composition.
Lithia, carbonate of	37.2	Lithia 16.5 + carb. ac. 20.7
—— chlorate	87.5	Lithia 16.5 + chl. acid 71
—— nitrate	67	Lithia 16.5 + nitr. acid 50.5
—— phosphate	42.5	Lithia 16.5 + phos. acid 26
—— sulphate	54	Lithia 16.5 + sulp. acid 37.5
Lithium	9	
—— chloride	42.5	Lith. 9. + chlor. 33.5
—— oxide	16.5	Lith. 9. + oxy. 7.5
Magnesia	18.5	Magnesium 11 + oxy. 7.5
—— acetate.....	66.5	Mag. 18.5 + acetic acid 48
—— arseniate	86	Magn. 18.5 + ars. ac. 66.5
—— borate	38.5	Mag. 18.5 + bor. acid 20
—— carbonate	39.2	Mag. 18.5 + carb. acid 20.7
—— bicarbonate.....	59.9	Mag. 18.5 + carb. acid 41.4
—— chlorate	89.5	Mag. 18.5 + chlor. acid 71
—— citrate	74.3	Mag. 18.5 + citr. acid 55.8
—— hydrate	27	Magn. 18.5 + water 8.5
—— hydriodate	137.2	Magn. 18.5 + hyd. acid 118.7
—— muriate	53	Magn. 18.5 + mur. acid 34.5
—— nitrate	69	Magn. 18.5 + nitr. acid 50.5
—— oxalate	54	Mag. 18.5 + ox. ac. 35.5
—— phosphate	44.5	Magn. 18.5 + phos. acid 26
—— succinate.....	65.8	Magn 18.5 + succin. acid 47.3

Substances.	Equivalent Number.	Composition.
Magnesia, sulphate of	56	Magn. 18.5 + sulp. acid 37.5
—— —— crystallized	115.5	Sulp. magn. 56 + water 59.5
—— sulphite	48.5	Magn. 18.5 + sulp. acid 30
Magnesium	11	
—— chloride	44.5	Magn. 11. + chlorine 33.5
—— oxide	18.5	Magn. 11 + oxyg. 7.5
Manganese	28.5	
—— acetate.....	84	Ox. man. 36 + acet. ac. 48
—— arseniate.....	102.5	Ox. man. 36 + ar. ac. 66.5
—— carbonate	56.7	Ox. mang. 36 + carb. ac. 20.7
—— chloride	62	Mang. 28.5 + chlorine 33.5
—— citrate	91.8	Ox. mang. 36 + citr. ac. 55.8
—— muriate	63	Ox. mang. 28.5 + mur. ac. 34.5
—— nitrate.....	86.5	Ox. mang. 36 + nit. acid 50.5
—— oxalate	71.5	Ox. man. 36 + ox. ac. 35.5
—— oxide 1st	36	Mang. 28.5 + oxygen 7.5
—— —— 2nd	39.7	Mang. 28.5 + oxygen 11.25
—— —— 3d peroxide ..	43.5	Mang. 28.5 + oxygen 15
—— phosphate.....	62	Ox. mang. 36 + phos. acid 26
—— phosphuret	39.5	Mang. 28.5 + phosphorus 11
—— succinate	83.3	Ox. man. 36 + suc. acid 47.3
—— sulphate	73.5	Ox. mang. 36 + sulp. acid 37.5
Marble	47.2	Lime 26.5 + carb. acid 20.7
Mercury.....	190	

Substances.	Equivalent Number.	Composition.
Mercury, acetate of	245.5	Ox. mer. 197.5 + a. acid 48
—— arseniate	264	Ox. mer. 197.5 + ars. ac. 66.5
—— perarseniate	338	Ox. mer. 205 + ars. ac. 133
—— borate	217.5	Ox. mer. 197.5 + bor. ac. 20
—— perborate	245	Ox. mer. 205 + bor. ac. 40
—— carbonate	218.2	Ox. mer. 197.5 + car. ac. 20.7
—— bicarbonate	246.4	Ox. mer. 205 + carb. ac. 41.4
—— chloride	223.5	Mer. 190 + chlo. 33.5
—— bichloride..... ...	257	Mer. 190 + chlorine 67
—— citrate	253.3	Ox. mer. 197.5 + citr. acid 55.8
—— cyanuret	238.8	Mer. 190 + cyan. 48.8
—— hydriodate.....	316.2	Ox. man. 197.5 + hyd. ac. 118.7
—— iodide	307.7	Mer. 190 + iodine 117.7
—— —— per	425.4	Mer. 190 + iodine 235.4
—— nitrate	248	Ox. m. 197.5 + nit. ac. 50.5
—— pernitrate	306	Ox. m. 205 + nit. ac. 101
—— supernitrate	460.5	Ox. m. 410 + n. ac. 50.5
—— oxalate.....	233	Ox. mer. 197.5 + oxal. ac. 35. 5
—— oxide....	197.5	Mer. 190 + oxy. 7.5
—— peroxide	205	Mer. 190 + oxy. 15
—— phosphate.....	223.5	Ox. m. 197.5 + p. acid 26
—— perphosphate	257	Ox. m. 205 + p. acid 52
—— sulphate.....	235	Ox. m. 197.5 + sulp. ac. 37.5
—— persulphate	280	Ox. m. 205 + sulp. ac. 75

Substances.	Equivalent Number.	Composition.
Mercury, subsulphate of ..	242.5	Ox m. 205 + sulp. ac. 37.5
—— sulphite	227.5	Ox. m. 197.5 + sul. ac. 30
—— sulphuret	205	M. 190 + sulphur 15
—— bisulphuret	220	Mercury 190 + sulphur 30
—— tartrate	260	Ox. mer. 197.5 + tar. ac. 62.5
—— tartrate and potash ..	367.5	Ox. mer. 197.5 + tar. ac. 125 + p
Molybdate of ammonia	82.5	Amm. 16 + m. ac. 66.5
—— lead	171	Ox. lead 104.5 + m. ac. 66.5
—— potash	111.5	Potash 45 + m. ac. 66.5
—— soda	96	Soda 29.5 + m. ac. 66.5
Molybdenum	44	
—— 1st oxide	51.5	Molyb. 44 + oxy. 7.5
—— 2nd ditto	59	Molyb. 44 + oxy. 15
—— 3d ditto	66.5	Molyb. 44 + oxy. 22.5
—— sulphuret	74	Molyb. 44 + sulp. 30
Nickel	28	
—— borate	55.5	Ox. n. 35.5 + bor. ac. 20
—— carbonate	56.2	Ox. nic. 35.5 + car. ac. 20.7
—— chloride	61.5	Nic. 28 + chlor. 33.5
—— citrate	91.3	Ox. n. 35.5 + cit. ac. 55.8
—— ferro-sulphate	144	Ox. n. 35.5 + sul. ac. 75 + ox. ir.
—— hydrate	44	Ox. nick. 35.5 + water 8.5
—— iodide	145.7	Nick. 28 + iod. 117.7

Substances.	Equivalent Number.	Composition.
Nickel, nitrate of	86	Ox. nick. 35.5 + n. ac. 50.5
—— oxalate	71	Ox. nick. 35.5 + ox. ac. 35.5
—— oxide	35.5	Nick. 28 + oxy. 7.5
—— phosphate	61.5	Ox. nick. 35.5 + phos. ac. 26
—— phosphuret.....	39	Nick. 28 + phos. 11
—— sulphate.....	73	Ox. nick. 35.5 + sulp. ac. 37.5
—— —— crystallized	132.5	Sulp. nick. 73 + water 59.5
—— sulphuret	43	Nick. 28 + sulp. 15
—— tartrate	98	Ox. nick. 35.5 + tar. ac. 62.5
Nitrous gas ..... or Nitric oxide	28	Nitr. 13 + oxy. 15
Nitrogen	13	
—— chloride of	147	Nitr. 13 + chlorine 134
Nitrous oxide	20.5	Nitr. 13 + oxy. 7.5
Olefiant gas	6.7	Carb. 5.7 + hydr. 1
Oxygen	7.5	
Oxychloric acid	86	Chlorine 33.5 + oxy. 52.5
Phosphuretted hydrogen	12	Phos. 11 + hydr. 1
Phosphorus	11	
—— sulphuret of	37	Phos. 22 + sulphur 15
Platinum	90?	
—— muriate	?	
Potash (dry).....	45	Potassium 37.5 + oxy. 7.5

Substances.	Equivalent Number.	Composition.
Potash, acetate of	93	Potash 45 + acet. acid 48
—— ammonio-sulphate ..	136	Pot. 45 + sulp. ac. 75 + amm
—— arseniate	111.5	Pot. 45 + ars. acid 66.5
—— binarseniate	178	Potash 45 + arsen. acid 133
—— arsenite	104	Potash 45 + arsenious acid 59
—— benzoate	157	Potash 45 + benzoic acid 112
—— borate	65	Pot. 45 + bor. ac. 20
—— carbonate	65.7	Potash 45 + carb. acid 20.7
—— bicarbonate.....	86.4	Potash 45 + carb. ac. 41.4
—— —— crystallized	94.9	Dry salt 86.4 + water 8.5
—— chlorate	116	Potash 45 + chl. ac. 71
—— chromate	88.5	Potash 45 + chromic acid 43.5
—— citrate	100.8	Potash 45 + citr. ac. 55.8
—— columbate	191 5	Potash 45 + col. acid 146.5
—— fluate	61 ?	Potash 45 + fluor. acid 16
—— gallate	104.7	Pot. 45 + gall. acid 59.7
—— hydrate	53.5	Potash 45 + water 8.5
—— hydriodate	163.75	Pot. 45 + hyd. ac. 118.75
—— hydrosulphuret	61	Pot. 45 + sulphuretted hydrog
—— hypophosphite	?	
—— hyposulphite	?	
—— iodate	200.2	Pot. 45 + iod. ac. 155.2
—— molybdate	111.5	Pot. 45 + mol. acid 66.5
—— muriate	71	Potassium 37.5 + chlorine 33

Substances.	Equivalent Number.	Composition.
Potash, nitrate of	95.5	Pot. 45 + nit. ac. 50.5
—— nitrite	88	Potash 45 + nitrous acid 43
—— oxalate.....	80.5	Potash 45 + oxal. acid 35.5
—— binoxalate	116	Pot. 45 + ox. acid 71
—— superoxalate	116	Pot. 45 + ox. acid 71
—— quadroxalate	187	Potash 45 + ox. ac. 142
—— oxychlorate.....	131	Potash 45 + oxy. chl. ac. 86
—— oxymuriate.....	116	Potash 45 + chloric acid 71
—— phosphate	71	Potash 45 + phos. ac. 26
—— biphosphate	97	Potash 45 + phos. acid 52
—— subphosphate.....	116	Potash 90 + phos. acid 26
—— superphosphate.....	97	Pot. 45 + phos. acid 52
—— phosphite	63.5	Pot. 45 + phos. ac. 18.5
—— subcarbonate	65.7	Potash 45 + carb. ac. 20.7
—— succinate.....	92.3	Potash 45 + suc. acid 47.3
—— sulphate	82.5	Pot. 45 + sulp. ac. 37.5
—— bisulphate	120	Potash 45 + sulp. acid 75
—— supersulphate	120	Pot. 45 + sulp. acid 75
—— sulphite	75	Pot. 45 + sulp. ac. 30
—— tartrate	107.5	Potash 45 + tar. acid 62.5
—— bitartrate.....	170	Potash 45 + tar. acid 125
—— supertartrate	170	Pot. 45 + tar. acid 125
—— tungstate.....	157.5	Potash 45 + tung. acid 112.5

Substances.	Equivalent Number.	Composition.
Potassium	37.5	
—— chloride	71	Pot. 37.5 + chlo. 33.5
—— iodide	155.25	Potassium 37.5 + iodine 117.75
—— peroxide	60	Potassium 37.5 + oxygen 22.5
—— phosphuret	48.5	Pot. 37.5 + phosp. 11
—— protoxide	45	Potassium 37.5 + oxygen 7.5
—— sulphuret	52.5	Pot. 37.5 + sulp. 15
Prussic gas	24.4	Carb. 11.4 + nitrog. 13
—— acid	25.4	Carb. 11.4 + nitr. 13 + hy. 1
Selenium	37.5	
—— acid	52.5	Selen. 37.5 + oxygen 5
—— oxide	45	Selen. 37.5 + oxygen 7.5
—— sulphuret	120	Selenium 75 + sulphur 45
Silica	30?	Silicium 15 + oxygen 15
Silicium	15?	
Silver	102.5	
—— acetate	158	Ox. silv. 110 + acet. acid 48
—— arseniate	176.5	Ox. silv. 110 + ars. ac. 66.5
—— carbonate	130.7	Ox. silv. 110 + carb. ac. 20.7
—— chloride	136	Silver 102.5 + chlorine 33.5
—— chromate	153.5	Ox. silv. 110 + chr. acid 43.5
—— citrate	165.8	Ox. silv. 110 + citr. acid 55.8
—— cyanuret	151.3	Silv. 102.5 + cyanog. 48.8

Substances.	Equivalent Number.	Composition.
Silver, molybdate of	176.5	Ox. silv. 110 + m. a. 66.5
—— nitrate	160.5	Ox. silv. 110 + nitr. ac. 50.5
—— oxalate.....	145.5	Ox. silv. 110 + ox. ac. 35.5
—— oxide	110	Silver 102.5 + oxyg. 7.5
—— phosphate	136	Ox. silv. 110 + p. a. 26
—— phosphuret.....	113.5	Silver 102.5 + phosp. 11
—— sulphate	147.5	Ox. silv. 110 + s. ac. 37.5
—— sulphuret	117.5	Silver 102.5 + sulp. 15
—— tartrate	172.5	Ox. s. 110 + tar. acid 62.5
—— tartrate of, and potash	280	Ox. s. 110 + tar. ac. 125 + pot. 45
—— tungstate	222.5	Ox. s. 110 + tung. ac. 112.5
Soda	29·5	Sodium 22 + oxy. 7.5
—— acetate	77.5	Soda 29.5 + ac acid 48
—— arseniate.....	96	Soda 29.5 + ars. ac. 66 5
—— arsenite	88.5	Soda 29.5 + arsenious acid 59
—— benzoate.....	141.5	Soda 29.5 + ben. ac. 112
—— borate	49.5	Soda 29.5 + bor. acid 20
—— carbonate	50.2	Soda 29.5 + carb. ac. 20.7
—— bicarbonate.....	70.9	Soda 29.5 + car. ac. 41.4
—— chlorate	100.5	Soda 29.5 + chl. acid 71
—— oxychlorate	115.5	Soda 29.5 + chl. acid 86
—— chromate	73	Soda 29.5 + chrom. acid 43.5
—— citrate	85.3	Soda 29.5 + citr. acid 55.8
—— fluate.....	45.5	Soda 29.5 + fluor. acid 16

Substances.	Equivalent Number.	Composition.
Soda, hydrate of	38	Soda 29.5 + water 8.5
—— iodate	184.75	Soda 29.5 + iod ac. 155.25
—— molybdate.....	96	Soda 29.5 + mol. acid 66.5
—— muriate.....	64	Soda 29.5 + mur. acid 34.5
—— oxymuriate	100.5	Soda 29.5 + chlo. acid 71
—— nitrate	80	Soda 29.5 + nitr. ac. 50.5
—— oxalate	65	Soda 29.5 + ox. acid 35.5
—— phosphate.....	55.5	Soda 29.5 + phos. acid 26
—— biphosphate	81.5	Soda 29.5 + phos. acid 52
—— phosphite	48	Soda 29.5 + phos. acid 18.5
—— succinate	76.8	Soda 29.5 + suc. acid 47.3
—— sulphate	67	Soda 29.5 + sulp. ac. 37.5
—— —— crystallized	152	Sulp. soda 67 + water 85
—— bisulphate	104.5	Soda 29.5 + sulp. ac. 75
—— sulphite.....	59.5	Soda 29.5 + sulp. ac. 30
—— sulphuret	37	Sodium 22 + sulphur 15
—— tartrate	92	Soda 29.5 + tar. ac. 62.5
—— —— and potash	199.5	Soda 29.5 + tar. ac. 125 + pot. 45
—— tungstate	142	Soda 29.5 + tung. acid 112.5
Sodium	22	
—— chlorate	100.5	Ox. sod. 29.5 + chlor. ac. 71
—— chloride.....	55 5	Sod 22 + chlor. 33.5
—— iodide	139.75	Sod. 22 + iod. 117.75
—— peroxide	33.25	Sod. 22 + oxy. 11.25

Substances.	Equivalent Number.	Composition.
Sodium, phosphuret of.....	33	Sod. 22 + phos. 11
—— sulphuret	37	Sod. 22 + sulp. 15
Strontites	52	Strontium 44.5 + oxy. 7.5
—— acetate	100	Stron. 52 + ac. ac. 48
—— arseniate	118.5	Strontites 52 + ars. acid 66.5
—— borate	72	Strontites 52 + bor. acid 20
—— carbonate	72.7	Strontites 52 + carb. acid 20.7
—— chlorate.....	123	Strontites 52 + chlor. acid 71
—— citrate	107.8	Stron. 52 + citr. ac. 55.8
—— hydrate.....	60.5	Strontites 52 + water 8.5
—— iodate	207.2	Strontites 52 + idr. acid 155.2
—— muriate.....	86.5	Strontites 52 + mur. ac. 34.5
—— nitrate	102.5	Strontites 52 + nit. ac. 50.5
—— oxalate	87.5	Stron. 52 + ox. ac. 35.5
—— phosphate.....	78	Strontites 52 + phos. acid 26
—— succinate	99.3	Stron 52 + succin. acid 47.3
—— sulphate	89.5	Stron. 52 + sulp. acid 37.5
—— sulphite	82	Stron. 52 + sulphurous acid 30
—— tartrate.....	114.5	Strontites 52 + tar. ac. 62.5
Strontium	44.5	
—— chloride.....	78	Stron. 44.5 + chlor. 33.5
—— iodide	162.2	Stron. 44.5 + iodine 117.7
—— oxide.....	52	Stron. 44.5 + oxy. 7.5
—— phosphuret	55.5	Stront. 44.5 + phos. 11

Substances.	Equivalent Number.	Composition.
Strontium, sulphuret of ...	89.5	Stront. 44.5 + sulp. 15
Sulphur	15	
Sulphuretted hydrogen	16	Sulphur 15 + hydrog. 1
Tannate of lead	304.5	Tannin 200 + ox. lead 104.5
Tellurium	36.5	
—— chloride	70	Tellurium 36.5 + chl. 33.5
—— oxide	44.0	Tellurium 36.5 + oxy. 7.5
Tin	55.5	
—— acetate	111	Ox. tin 63 + acet. acid 48
—— arseniate	129.5	Ox. tin 63 + ars. acid 66.5
—— chloride 1st	89	Tin 55 5 + chlorine 33.5
—— chloride 2nd	122.5	Tin 55.5 + chlorine 67
—— citrate	118.8	Ox. tin 63 + citr. acid 55.8
—— muriate	97.5	Ox. tin 63 + mur. ac. 34.5
—— permuriate	139.5	Ox. tin 70.5 + m. ac. 69
—— nitrate	113.5	Ox. tin 63 + nit. ac. 50.5
—— oxalate	98.5	Ox. tin 63 + ox. acid 35.5
—— oxide	63	Tin 55.5 + oxyg. 7.5
—— oxide 2nd	70.5	Tin 55.5 + oxy. 15
—— phosphuret	66.5	Tin 55.5 + phosp. 11
—— succinate	110.3	Ox. tin 63 + suc. acid 47.3
—— sulphate	100.5	Ox. tin 63 + sulp. ac. 37.5

Substances.	Equivalent Number.	Composition.
Tin, sulphuret of	70.5	Tin 55.5 + sulp. 15
—— tartrate	125.5	Ox. tin 63 + tar. acid 62.5
Tungsten	90	
—— tungstic acid	112.5	Tung. 90 + oxyg. 22.5
—— lime	139	Tung. acid 112.5 + lime 26.5
—— manganese	148.5	Tung. acid 112.5 + ox. mang. 36
Uric acid	33	
Water	8.5	Oxyg. 7.5 + hydrog. 1
Yttrium.....	30	
Yttria.....	37.5	Yttrium 30 + oxyg. 7.5
Zinc	33	
—— acetate.....	88.5	Oxide zinc 40.5 + acet. acid 48
—— arseniate.....	107	Ox. zinc 40.5 + ars. ac. 66.5
—— borate	60.5	Ox. zinc 40.5 + bor. ac. 20
—— carbonate	61.2	Ox. zinc 40.5 + carb. ac. 20.7
—— chlorate	111.5	Ox. zinc 40.5 + ch. ac. 71
—— chloride	66.5	Zinc 33 + chlorine 33.5
—— citrate	96.3	Ox. zinc 40.5 + citr. ac. 55.8
—— muriate	75	Ox. zinc 40.5 + mur. ac. 34.5
—— nitrate	91	Ox. zinc 40.5 + n. a. 50.5
—— oxalate	76	Ox. zinc 40.5 + ox. ac. 35.5
—— oxide	40.5	Zinc 33 + oxyg. 7.5

Substances.	Equivalent Number.	Composition.
Zinc, phosphate of	66.5	Ox. zinc 40.5 + ph. ac. 26
—— phosphuret.....	44	Zinc 33 + phosp. 11
—— succinate.....	87.8	Ox. zinc 40.5 + suc. acid 47.3
—— sulphate	78	Ox. zinc 40.5 + sulp. ac. 37.5
—— —— crystallized	137.5	Sulph. zinc 78 + water 59.5
—— sulphite	70.5	Ox. zinc 40.5 + sulp. ac. 30
——sulphuret.....	48	Zinc 33 + sulp. 15
—— tartrate	103	Ox. zinc 40.5 + tar. ac. 62.5
Zirconium.....	35	
Zirconia.....	42.5	Zinc 35 + oxyg. 7.5

A LIST OF THE WORKS

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TO BOTH THE VOLUMES.

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THE END.

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CORRIGENDA.

Vol. I. *Page* 38, *line* 1 of the note, *for* chlorate *read* chloride.
—— 40, *line* 20, *for* tartareous *read* tartaric.
—— 65, *line* 20, *for* arterial *read* venous.
—— 66, *line* 7, *after* caloric *add* and is converted into water.
—— 79, *line* 12, *for* incipient *read* slow.
—— 264, *line* 28, *dele the word* linseed.
—— 284, *line* 7, *for* oxymuriate *read* chloride.
—— 314, *line* 20 et passim, *for* cauk *read* cawk.
—— 351, *line* 18, *for* 55.5 *read* 55.8 and consequently 128.3
—— 352, *line* 21, *for* it is a supermalate *read* it has an acid taste.
—— 354, *line* 13, *for* 46.7 *insert* 47.3
—— 393, *line* 1, *for* non-conductor *read* conductor.
—— 422, *line* 2 of the note, *for* page 270, *read* pages 165 & 237.
—— 427, *note* [m], *for* page 25, *read* page 33.
—— 470, *line* 4, *dele the words* slowly, and.
—— 520, *line* 21, *for* Rabe, *read* Rabel.
note [m], *for* page 41 *read* page 40.
—— 574, *line* 24, *for* precipitated from their solutions by, *read* decomposed by.
—— 578, *line* 2, *for* 55.5 *read* 55.8
—— 626, *line* 41, *for* page 63 *read* page 59.

Vol. II. *Page* 29, *line* 6, *for* saturating *read* decomposing.
—— 30, *line* 8, *for* rapidly *read* slightly.
—— 39, *line* 15, *for* calcines *read* combines.
—— 44, *line* 27, *for* rendered neutral *read* neutralised.
—— 62, *line* 2, *for* any *read* must.
—— 55, *line* 4, *for* super *read* sub
—— 67, *line* 10, *for* salts *read* compounds.
—— 481, *note* [n], *for* page 117 *read* page 127.

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